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RESEARCH MEMORANDUM

REVISED STUDY OF PIONEER RECONNAISSANCE BY BALLOONS

by

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SUMMARY

The "Gopher system" is designed to provide broad aerial photographic coverage by balloon-borne cameras. The system includes the launching facilities, the balloon vehicle and its associated gear, and the recovery network. The balloons are capable of floating in the stratosphere, above 60,000 ft, for periods of at least six to eight days. For this period the west winds, during the winter season, will carry them roughly 5,000 to 10,000 miles. There is no way of controlling the trajectories of these balloons, so the photographic coverage will consist of strip photos extending randomly downwind from the launching points. The cameras will be turned off at night, and there will be many areas where the cloud cover obscures the ground, therefore these strips will not be continuous.

Taking into account the failure to get pictures because of cloud cover and darkness, and failure to recover the film due to malfunction of equipment or adverse trajectories, the fraction of the entire area of western and central Russia which could be photographed with a given number of balloons is shown in Fig. 1. There will actually be considerable overlapping of pictures in the middle of the area due to the random nature of the trajectories, and the coverage will tend to be poorer in the northern part of Russia.

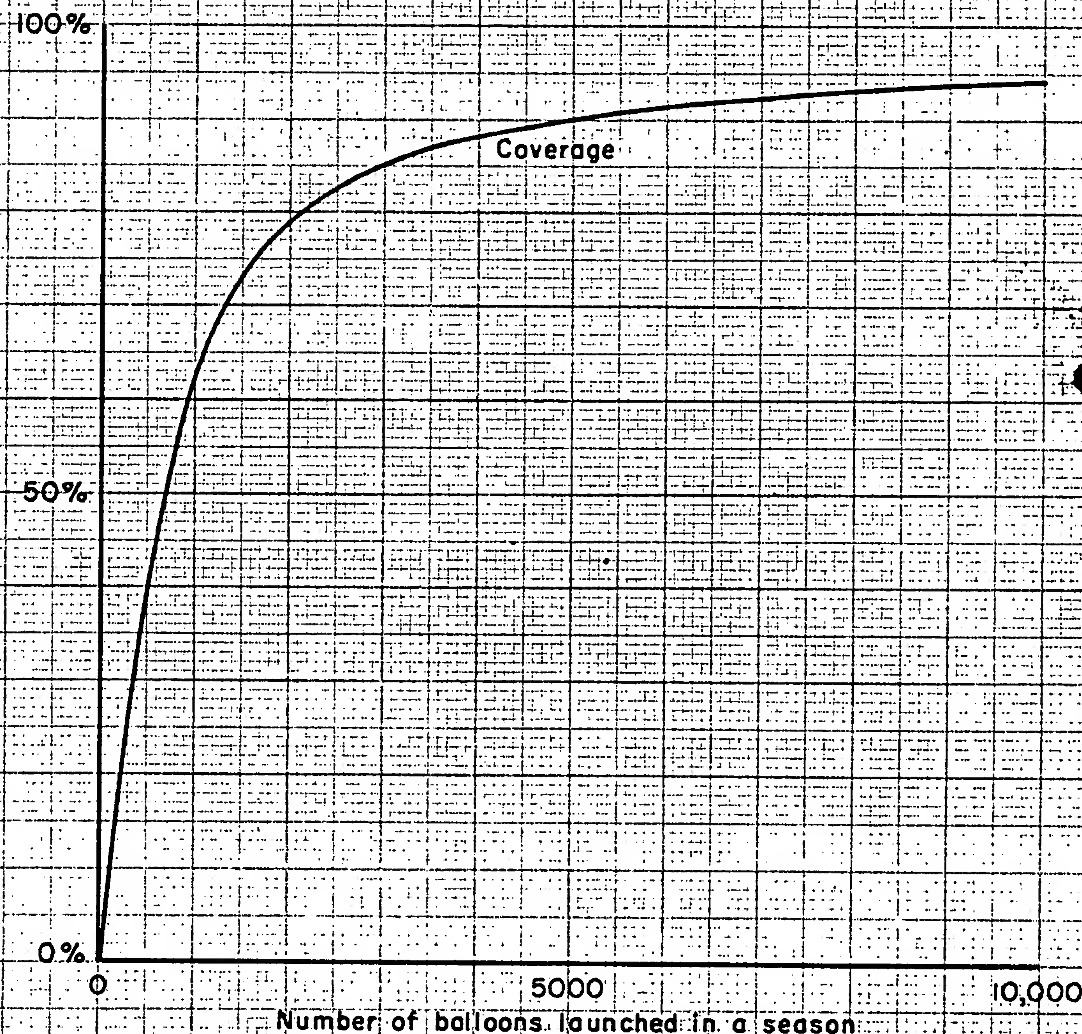

Fig. 1 — Percent coverage of the USSR west of longitude 100°E by balloons launched from latitude 65°N, longitude 0°

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In order to estimate the requirements of the Gopher system for a given number of balloons launched and recovered, it has been necessary to develop a fairly complete model of the system based on the components which have been developed under Project Gopher. Using this as a basis for the analysis, the explicit dollar costs of the following have been estimated:

- The expendable gear, including the camera, beacons, balloon, etc.
- The lifting gas
- The special ground equipment required for launching
- The radio DF network required for recovery
- The operation of the recovery aircraft.

These costs, as a function of number of balloons launched, are shown in Fig. 2.

The cost of the training of specialized personnel, of maintaining launching bases, of procuring and allocating the recovery aircraft, of transporting the task forces, etc. have not been found explicitly. Figure 2, however, shows some requirements in terms of men, aircraft, lifting gas, and number of launching crews, which indicate the size of the undertaking for a given number of balloons.

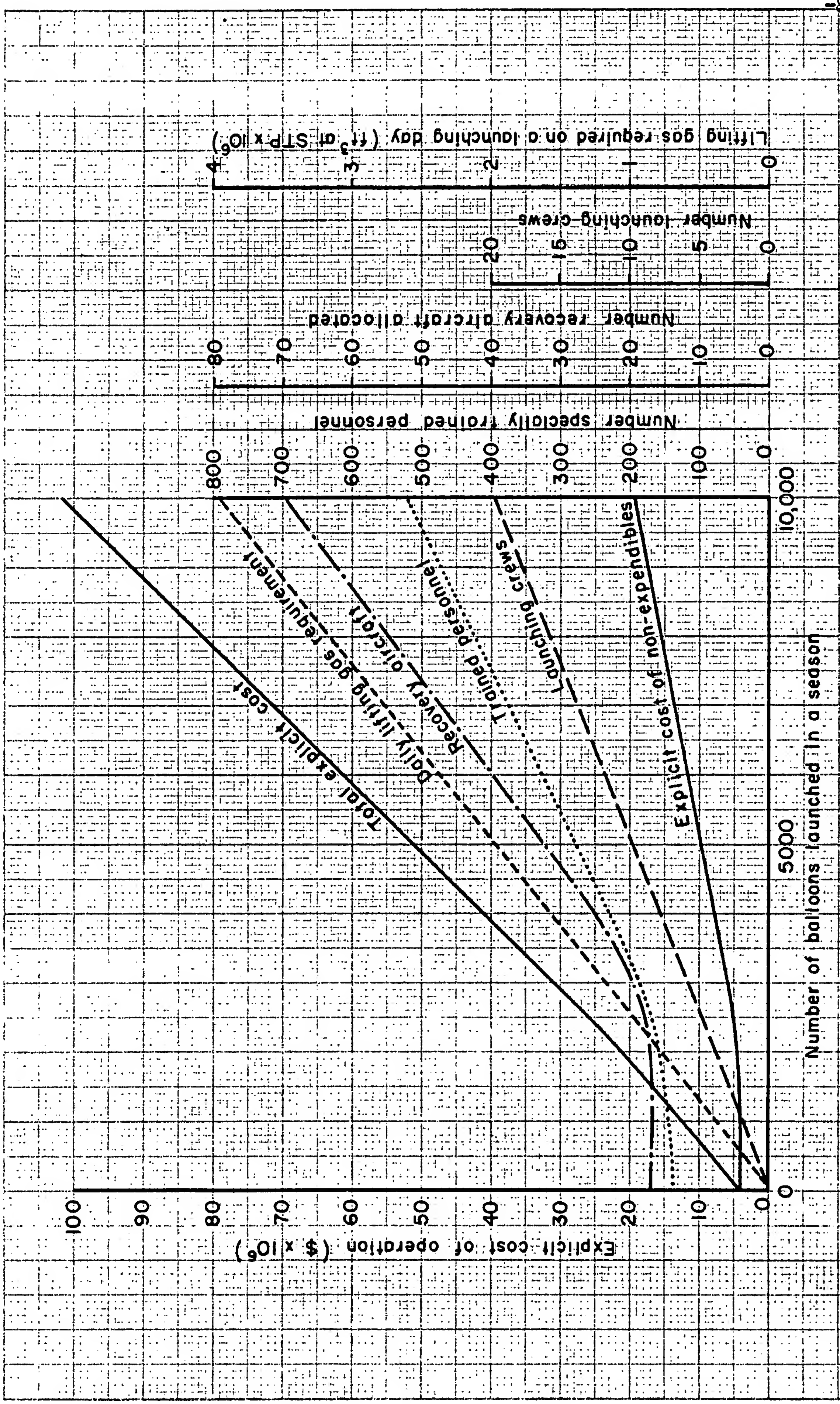

Fig. 2 — Estimates of requirements and cost as a function of number of balloons launched

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The conclusion of this analysis, as can be seen from Figs. 1 and 2, is that a Gopher operation of less than about 1000 balloons will require a large effort (mostly in the recovery operation), and will yield less than 60% coverage of Russia. With relatively little increase in effort, except for the added cost of the expendable gear, an operation of some 2000 to 5000 balloons will yield 80% to 90% coverage. The increase in coverage by going to still larger numbers of balloons is not significant, particularly for the central part of Russia, which will have practically 100% coverage with more than 2000 balloons.

The model of the Gopher system which was used as the basis for the cost analysis is described in some detail, and in certain respects it may represent the final operational system quite well. However, it should not be used as the basis for an operational plan without more consideration of the complex factors involved.

Under Project Gopher most of the components of the Gopher system have been developed and tested, with a few important exceptions. It is generally felt that the operation could be conducted using present equipment, but a major program would have to be undertaken to coordinate and combine the various components of the research and development phase into a complete system. Such a program, if undertaken energetically, should result in an operational capability in about one year.

REVISED STUDY OF PIONEER RECONNAISSANCE BY BALLOONS

I. Introduction

In November, 1950, at the request of the Air Force Scientific Advisory Board, RAND made a preliminary study of the feasibility of pioneer reconnaissance by balloon-borne cameras. The conclusion of the study was that such a system appeared to be feasible, subject to the successful development of certain components and techniques (RM-494, Top Secret). A crude estimate of the cost of a balloon reconnaissance operation over the U.S.S.R. ran from 22.5 million to 135 million dollars. The lower estimate was for 1500 launchings, resulting in about 30 percent coverage of west-central Russia, and the larger estimate was for 9000 launchings, resulting in about 90 percent coverage of the same area.

A major research and development effort was begun shortly after the completion of the RAND study, under the general name of Project Gopher (though there were supporting projects under different names, such as Project Moby Dick). In the course of the work by a number of agencies more insight was gained into the factors involved in such a reconnaissance system, and a few of the original RAND estimates turned out to be either optimistic or pessimistic.

At the request of the Office of Development Planning, DCS-Development, the present study was undertaken to reascertain the feasibility and cost of a balloon reconnaissance system. Much of the discussion in the original RAND study still applies and is not repeated here. This report is, therefore, in the nature of an "addendum" to RM-494, though it is organized in such a way that it will not be necessary to refer to the original in order

to understand the major conclusions.

It should be emphasized that, although no complete balloon reconnaissance system has ever functioned in its entirety, every component of the system has now been investigated to some extent by actual field tests. The conclusions arrived at in this report may be somewhat in error due to lack of sufficient quantitative data on which to base them, but it can now be said with certainty that no single component is unproven. It is no longer necessary to guess in the dark about such factors as balloon endurance, recovery techniques, camera operation, etc., so the present estimate is probably more reliable than the original one made two years ago.

II. Project Gopher Results and Conclusions

A. Payload

The primary components of the gondola developed by the Stanley Aviation Company for the Gopher system are:

- Camera (K-17 aerial camera, modified)
- Position recorder (Records solar elevation angle)
- Timer (For camera and for control of beacons)
- Beacons (HF, for long range, and VHF)
- Release mechanism (Receiver and decoder)
- Ballast control
- Heater (Hydrogen peroxide)

In addition there are the batteries, the ballast containers and valves, antennae, parachute, etc.

The total weight of the present payload, minus ballast, is about 460 lbs. It is considered by the designers that this may be reduced to less than 400 lbs in the later versions using the K-17 camera. With improved camera equipment, built especially for the balloon application, the camera and film weight could be reduced by another 20 lbs or so, and the lower power requirement may mean less weight in batteries. (See Section IV. C.) It is difficult to determine the ultimate minimum weight, but it will probably be between 300 and 350 lbs, this being required for the batteries, beacons, timers, and associated gear, plus the insulated compartment.

The estimated cost of the present type gondola, exclusive of the government-furnished camera and solar elevation angle recorder is about $4000 to $4500 per gondola in production lots of 3000 or more. The total cost of the payload (exclusive of balloon) is about $7000.

B. Attrition to Enemy Action

The vulnerability to enemy action clearly depends upon two factors:

- o With what success will the enemy detect and track these balloons?
- o Having located the balloon, with what success can he bring them down?

1. Detection

The conclusions of the original RAND study remain essentially unchanged. A systematic visual detection of these balloons is unlikely, even if a corps of observers is alerted to scan the sky. This is because the eye does not easily acquire a small object in the sky, as it is not focused properly when looking at the blank sky. Moreover, cloud cover will prevent any observations at all from 50 to 85 percent of the time in winter. Once the balloon is spotted on a clear day, then it may be possible to follow it visually, since the balloon as seen from the ground is several times the minimum angular resolution of the eye, even at a distance of ten miles from the position of the balloon. The absolute maximum horisontal range for visual tracking with the unaided eye during the day is about thirty miles. Under clear conditions at sunrise or sunset, when the sky is darkened but the balloon is still in the sunlight, the high contrast between balloon and sky makes the balloon stand out very clearly, even brighter than the planet Venus. This "light bulb effect" will occasionally be noticed by some people on the ground, though only for a short time each day. Thus, the presence of the balloons will certainly be noticed, but it will be nearly impossible for a visual observation network to provide consistent tracking information for the purpose of interception.

The radar detection of these balloons is uncertain and depends on several controllable factors. The radar range of a balloon with an 85 foot

trailing wire, as seen by a type of Russian radar which operates on about 150 Mc with vertical polarization (modified Freia type), would be at least equivalent to a large bomber, since the antenna is long enough to provide a large equivalent echoing area. The VHF homing antennas, which are now cut for 150.12 Mc would provide very large echoing areas also, since they are of just the right length to form a tuned dipole for this type of radar. Detection by horizontally polarized VHF radars (Dumbo type) or by microwave radars would not be so easy. In fact, experience with tracking these balloons by U.S. S-band and L-band radars has generally indicated that they will not be detected initially by such radars, and will only be tracked with difficulty at short ranges <u>after</u> they have been located. Part of the difficulty in locating these balloons arises from their great altitude, which carries them above the usual radar antenna pattern.

Appendix A contains a discussion of some possible countermeasures against VHF radars to reduce the chance of radar detection. Whether it will pay to adopt these depends on whether the success of the enterprise requires non-detection. The answer to this obviously depends on whether they can be brought down once they are detected.

2. <u>Vulnerability</u>

The present payload, weighing about 460 lbs, can be set to float on a 73 ft balloon initially at between 55,000 and 60,000 ft. This assumes an initial 775 lbs of ballast and a gross load (including balloon weight) of 1500 lbs. (These are the specifications recently set by Hqs, ARDC, for the current system.) By reducing the payload weight (See Section II. A.) and ballast, it may be possible to reduce the gross load by about

300 lbs, and this would allow the same balloon to float initially at about 65,000 ft. Until a larger balloon is proven operationally practical, the 73 ft vehicle appears to be the maximum acceptable balloon size (see Section II. C.), and so these altitudes are also maximum initial altitudes for the present. Each day, assuming a non-leaking appendix, the gross load will decrease due to the dropping of ballast, and so the altitude will rise from 1500 to 2000 ft higher each day.

It is reasonable to assume that any large-calibre bullet (non-explosive) which touches the balloon will essentially "kill" the balloon. In order to stay aloft for six to eight days, the total allowable hole area in a 73 ft balloon is about .15 in^2. A bullet tearing a hole in the fabric will therefore at least double the normal leakage, and if this happens early in its flight it will never complete the trip.

The ceiling of our latest F-86 jet fighters is about 45,000 ft, and Russian MIG's have been reported flying some 5,000 ft higher. This means a possible 50,000 ft ceiling for current production fighters. Fighters equipped with afterburners could possibly gain another 5,000 ft altitude, so one should reckon with a potential Russian fighter ceiling of 55,000 ft. This means that, if all goes well, the balloons will probably not be shot down by fighter gunfire.

There is reason to believe that there could be a saving of ballast by allowing a slow descent during the night (the "solar engine" principle), particularly if specially designed balloons were used which could take on a load of air without this air mixing with the gas. This is practical from the balloon standpoint, but may seriously increase the vulnerability, since an early morning fighter interception would then be possible. Fortunately,

the required endurance can be achieved without recourse to the solar engine principle, and so there is no need for allowing the balloon to descend at night.

The conclusion of the original study with regard to ground fire or guided missiles is probably still valid. At present there are some anti-aircraft guns which probably could reach up to 55,000 ft and above if the balloon were nearly overhead, and with modified fire control they could have a 0.2 to 0.5 probability of kill per round. Air-to-air rockets or canon fired upwards from high flying aircraft might also be successful in shooting balloons down.

With one to three years' time the range of guided missiles and barrage rockets could be virtually unlimited, depending only on the desire of the Russians to develop a weapon to kill balloons. However, the cost of a missile program to effectively hamper a Gopher operation would be many times the cost of the balloon program. This cost to the enemy could be further increased by the use of large numbers of dummy balloons

3. Electronic Countermeasures

The enemy will attempt to tamper with the communication and control equipment of the balloon, and he will be effective in this if measures are not taken to anticipate it.

First, there is the command cut down system, and if it were not carefully designed and the command code kept a secret, the gondola could be released from the balloon before it ever reached the recovery area. However, it is possible to design a system which will respond only to a particular command, each balloon having a different "key" so that any attempt to bring the load down prematurely will fail. It must be so designed that the system will not

be compromised when some of the receiver and decoder units fall into enemy hands, as they surely will after the operation has been under way for awhile. In other words, the combination set into each unit must be sufficiently complex so that one has to know the exact combination in order to work it.

The present Stanley Aviation unit appears to provide the required security, but it would be well to let it be tested further by allowing a group of electronics experts try to break the combination in a simulated countermeasure campaign.

The recovery system may be very susceptible to enemy jamming of the DF signals. If this turns out to be the case, then the network may have to be moved away from the coast of Asia, to a line along the 180th meridian. Another alternative would be to rely on VHF signals instead of HF signals, which would be practical for the "picket" ship system of interception but not for the long range tracking and GCI system. (See Section II. D. 2.) It is fairly certain that an attempt will be made to jam the balloon signals, and serious consideration should be given to ways of preventing this from being effective. Some of these ways are discussed briefly in Appendix B.

Conclusions Concerning Attrition

The difficulties of initial detection, tracking, and weaponry which would have to be overcome by the Russians to knock down flights of balloons at 55,000 to 70,000 ft are formidable. With unmodified equipment and techniques they could probably do little against them. There is every reason to suppose, however, that the Russians will try to develop a weapons system as soon as they are aware of the balloon project, and such a system could become effective in a short time, though at considerable cost.

Ways of preventing jamming of the recovery system should be carefully studied.

C. The Balloon

1. History of the Development Program

At the inception of the Gopher program, there was available for use a 73 foot diameter balloon, 1 mil thick. This balloon had stayed aloft for a maximum of 36-48 hours, and had lifted loads of the order of 100 lbs to altitudes of ~ 100,000 feet. When the requirements were set forth, however, (see Appendix B) it was quickly learned that the available vehicle would not be adequate. This was due to two main reasons. First: The balloon of two years ago was not stressed for the required loads (~ 1500 lbs). Second: The diffussion of gas through the fabric was too high to allow the required duration. These were the main problems that had to be overcome and that were, in fact, surmounted in the time since the project began.

What has evolved from this intensive work is a balloon of approximately the same physical size (73 feet) that is capable of meeting the requirements as set forth in the Gopher program. It has been tested extensively, and is even now being used as the vehicle for the Moby Dick project (a large scale balloon flying program in the United States). It should be noted, however, that it was not chosen because it represents either the ultimate or optimum size, but rather because it is the largest <u>proven vehicle in existence today</u>. This "new" 73 foot balloon is 2 mils thick (laminated 1 mil sheets) and has a daily leakage rate of less than 5 percent of the remaining gross load. With a gross load of 1500 lbs this balloon will fly (initially) at an altitude of 58,000 feet, and, depending on the type of balloon appendix used, will either remain at this altitude throughout the trip or will climb progressively higher

each day.* Such a balloon carrying approximately the required gross load has been kept aloft for upwards of 5 days, the ballast weight being within the permissible limit of ballast weight on the operational Gopher flights. The cost of such a vehicle is approximately $1400 per balloon in small quantities. It is assumed that the unit cost would drop proportionately when ordered in lots of several thousand.

Also appearing as an outgrowth of this two year program is a somewhat larger balloon that was specifically designed for the Gopher project. This is a balloon that is 116 feet in diameter, and is capable of providing approximately 25 percent more lifting capability than the 73 foot balloon. Although not completely tested, this balloon has, on at least one occasion, lifted a load of 1700 lbs (gross load 2366 lbs) to 74,000 feet and kept it aloft for almost 9 days. As such, it is a vehicle that offers considerable promise for possible future operations.

2. The Launching Problem

The ability to launch a large balloon is dependent on the wind speed while it is still tied to the ground. Because the force due to the wind is approximately proportional to the cross sectional area of the balloon that is exposed to the air stream, one is led to the conclusion that the larger the balloon is, the greater will be the effect of the wind. When this is combined

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* As was pointed out in Appendix B, a balloon with an air tight appendix (no air mixing) will climb to a higher altitude each morning due to the decreased gross load. This is illustrated in Figs. 10 and 11. Although not completely tested, such an appendix has been designed by the University of Minnesota balloon group, and consists of a "pigtail" exhaust valve fastened to the top of the balloon and extending down one side.

with the fact that, in the absence of a shelter, an ordinary 73 foot balloon cannot be launched in wind speeds higher than ~ 2 knots, it is apparent that an operation involving balloons of this size (or larger) would be seriously hampered due to the high percentage of time that surface wind velocities are too great. This problem has been partially solved by a development of General Mills, Inc., called the "reefed balloon." In essence, this is a long, narrow tube of polyethelene that restrains almost all of the balloon except the bubble, and presents a smaller cross sectional area to the wind. If no weigh-off is required (establishing the free lift by actually balancing the gross load against the lift), it has been found that a 73 foot balloon can be launched in winds with gusts up to 15 knots. This value assumes a vertical launching, a necessary condition (to date) if heavy shock loads are to be kept off the balloon. It should be noted from Appendix B. 2 that, when calculated on the assumption of equivalent flat plate area, the forces due to the wind on a reefed 73 foot balloon and a reefed 116 foot balloon are approximately equal, a condition that was not possible without reefing, and which makes both vehicles appear equally feasible from the standpoint of launching.

It has been proven feasible to launch large balloons (73 feet) from ships at sea (escort carriers, sea plane tenders, etc.), as well as land bases. Table 2, Appendix B, compares the land base with the sea base from several aspects. As is shown in this table, the sea base, with its ability to establish a no-wind condition over the balloon in wind velocities up to the speed of the ship, has a slight climatological edge over the land base, which is generally limited to gust velocities of 15 knots. The sea base is also more secure from the standpoint of sabotage. The land base, however, appears

to be better suited from the standpoint of logistics, especially when considering the supplying of lifting gas. The necessary gas generation unit for a ship engaged in launching several thousand balloons is both cumbersome and expensive. Any improvement in the launching system that would allow land operations in gust velocities greater than 15 knots would make the land base somewhat more attractive than the sea base.

Experience has shown that the criteria for a successful launching system are as follows:

1. The system must be omnidirectional.
2. The system must provide for a minimum handling of the delicate material of the balloon, both by personnel and by foreign objects (canvas, ropes, walls, etc.).
3. The system must provide a minimum shock load on the balloon and gondola at launching.
4. There must not only be a minimizing of the direct wind force, but also of the burbling due to turbulence, which tends to place undue local stresses on the balloon.
5. There should be a minimum of mechanical gadgetry involved in the system, as these tend to reduce the overall reliability.

Many improved land launching systems have been proposed and several have been tried, but with only partial success. So far none has complied with all of the above criteria.

The launching question is therefore not completely solved. Both the land and the sea base are capable of doing the job, though much could be gained through improving the system. Only a cursory examination of the climatic factors

involved in launching has been made for this report. Therefore, a more detailed study should be conducted before choosing an operational base, taking into account not only the prevailing surface conditions but also the distribution of trajectories (see Section II. E.).

3. The Duration Problem

Although the launching problem, the supply problem, and the recovery problem are important in the overall program, the most important single parameter of the system must be the flight duration -- the ability of the balloon to stay aloft long enough to reach its destination. The former problems leave one some freedom of movement to exert a partial external control, but once a balloon is launched its ability to stay aloft for the required period depends entirely on what has been done before letting it loose.

The requirements, as set forth in Appendix B. 1. A., calls for a floating altitude of at least 58,000 feet, a take-off load of 1500 lbs, and an ultimate duration of 6-8 days. Although, as this appendix further shows, this requirement can be met now with the present 73 foot balloon, it is of interest to note how the duration could be increased, thereby increasing the margin of safety.

Duration is approximately proportional to the log of the ratio of fixed weight to total weight (fixed weight plus ballast). The obvious method of increasing the duration is therefore to decrease this ratio. This can be done by decreasing the payload and using this saving as ballast, or by decreasing both the payload and the total load. Both methods are under serious consideration, and it should be noted that the latter will make the launching and recovery operations somewhat easier.

The ultimate duration of a flight is determined by the amount of ballast

carried by the system and its daily rate of usage. The fractional daily ballast requirement is a function of two main happenings: First: A certain fraction of the gas will diffuse through the walls of the balloon and out of the appendix each day. To maintain altitude, this loss of lift must be compensated by an equal decrease in load. Second: Each balloon will lose a certain fraction of its lift due to a loss in "super heat" (heat gained through the absorption of solar radiation). This second cause occurs quite abruptly and must be accompanied by a sufficient ballast expenditure so as to keep the vehicle from descending to the ground.

The first cause has been almost completely eliminated, as stated, by laminating the balloon skin and improving the appendix. For this reason, it is assumed that no noticeable improvement in duration can be expected from research in this direction for the present.

Methods of decreasing the penalty one must now pay for the sunset effect are treated quite extensively in Appendix B.1.C. It is sufficient to say here that several promising possibilities do exist and are being pursued quite vigorously. These may be divided into two main categories:

- By slowing down the descent of the balloon by increasing its thermodynamic stability. Essentially this involves the use of air entrainment to keep the balloon at constant volume, and thereby increasing the work that the atmosphere must do on the balloon. General Mills, Inc. reports such an effect, which they call the "solar engine." Although not yet demonstrated, the people from the University of Minnesota are planning to improve this method still further by using a sealed gas

filled balloon enclosed in an unsealed ballonet which will fill with air as the system descends. It is easily seen that, if a balloon can be slowed down considerably by this method, the actual ballast expenditure will be greatly decreased.

- By reducing the balloon's reaction to solar radiation, thereby decreasing the change in lift due to a gain or loss of superheat. The reason for the present dependence on sunset is that the balloon is absorbent in the region of solar radiation. The people from the University of Minnesota have found that the tapes that help to hold the balloon together are one of the chief culprits in this respect, and they are therefore flying tapeless balloons. A second way of attacking this problem is to make the balloon dependent on the earth's radiation (which is mostly in the infrared region of the spectrum), and therefore no longer subject to a diurnal effect. This too is being tried, utilizing ammonia as the lifting gas, which has strong absorption bands in the infrared. With the latter method, it should be noted that a balloon that is so bound to the earth is subject to changes due to cloud decks and other such variations in the earth's radiational temperature which may be as great as the sunset change.

A third method of reducing ballast requirements has been considered theoretically in Appendix B.1.C. This involves the vaporizing of liquid ammonia and replacing the gas in the balloon rather than dropping ballast. On paper,

this looks very promising and appears to increase the duration for equally loaded balloons by as much as 40 percent.

CONCLUSION

The techniques described above offer considerable promise of increasing the ultimate performance of the balloon, but it should be emphasized that the vehicle in its present form appears to be capable of doing the job.

D. Recovery

The original study contained a fairly comprehensive discussion of the recovery factors, and will not be repeated here in detail. The three possible methods for recovering the balloon payload are:

- To snatch it from the air by a recovery plane
- To snatch it from the sea by a recovery plane
- To recover it from the sea by a surface craft

A fourth possibility has been mentioned, the recovery from land areas, but experience has shown that this requires the active cooperation of the civilian population, and is more or less uncontrollable and haphazard. Moreover, it would be stretching the range of the balloons to require them to reach the first friendly land mass, the North American Continent.

1. Air-Snatch Recovery Tests

The mid-air snatch is potentially the most economical, but up to a year ago it had never been tested systematically. Last summer the Aerial Pickup and Delivery Unit of the Equipment Laboratory, WADC, successfully demonstrated that a payload of up to 300 lbs hanging on a parachute can be snatched in mid-air and pulled into an aircraft. These remarkable tests were made at El Centro, California, using a C-119 "Packet" with the rear doors removed (as suggested in a RAND proposal).

Although the unadorned statistics of the tests show a low probability of success (See Appendix C.), the following are the conclusions of the test personnel and of the RAND observers (who flew in the pickup plane for several of the tests):

- With a reasonable development effort and the uninterrupted use of a plane of the C-119 type, this

method could be ironed out to give better than an 80 percent probability of recovery for those loads which were located and brought down successfully to the recovery altitude.

- Specially reinforced parachutes with heavy (1000 lb test) risers and reinforced skirts should be manufactured for this purpose. They should be perfectly stable and should be large enough to provide not more than 1000 ft per min. fall at recovery altitude. Parachute designers should be able to recommend the cheapest form of chute to meet these requirements. Incidentally, since the opening stresses on this chute are quite small, the fabric can be made of very light material, thereby saving weight. It should be red or orange for best visibility.
- The number of recoveries per flight could be quite large, subject only to the range of the aircraft. It will take about one-half to three-quarters of an hour to complete a recovery, once the aircraft has arrived at the balloon position.
- Weather conditions required for recovery are clear conditions at and above the recovery altitude, though high thin clouds would not be too serious. The parachute must be seen visually for the contact, and the range at which the chute can be seen under clear conditions is some five to ten miles. Although clear conditions above, say,

10,000 ft are not too prevalent in the Northwest Pacific in winter, it will usually be possible to wait until the balloon moves over a clear area.

2. Estimated Force Requirements

The force of aircraft required to do this recovery job for a full scale reconnaissance effort may be estimated in the following way:

- o Length of the recovery network, from Okinawa to Nome, is about 4000 n mi, extending to a curved line from SW to NE. (See Section E. 2.)
- o Bases at or near Okinawa, Tokyo, Shemya, and Nome (a minimum of four) should be able to provide coverage for the area (See Fig. 3.)
- o The fraction of aircraft out for maintenance at any one time is 1/3, and the abort rate is 0.8 (the usual factors considered in bombing campaign analysis). An extra stand-by aircraft is required to fill in for the aborts, one for each five operational aircraft at a given base.
- o The network is "saturated," i.e. there is always at least one balloon in the patrol area of each aircraft, so all sectors of the network must be continuously patrolled during the daylight hours.
- o Each aircraft can attempt to recover, on the average, five payloads on a day's operation. Thus, as the flux of balloons through the network increases there will be a point where more aircraft must be added to keep the average work load at five recoveries per aircraft per day. (The

maximum number of recoveries for a given aircraft might be as much as ten or fifteen per day, if they were quite closely spaced, but the average work load is kept low to allow for the random fluctuations in the number of balloons passing through a given sector.)

- The aircraft which would probably be best suited for this job is the C-119H "Packet." This ship with only its external fuel tanks has a combat radius, at around 5000 ft altitude, of 1250 mi, and an endurance of about twenty hours. With a light load consisting of the recovery gear and crew the range could be greatly increased by adding fuel tanks in the cargo space, as is now done for ferrying these aircraft. This will probably not be necessary, however. (Its normal cruising speed is 131 knots at 5000 ft, its maximum speed at 15,000 ft is 239 knots, and its combat ceiling is 28,000 ft.)
- The cost of flying such an aircraft, including the cost of fuel, maintenance, and depreciation, is estimated to be roughly $500 per flying hour. Each of the recovery aircraft flies an average of ten hours per operational day.
- The aircraft are grounded 10 percent of the time due to adverse base weather (an average for the network).
- About 10 percent of the balloons will never reach the network due to adverse trajectories (See Section E. 2 below).

- When an aircraft succeeds in reaching a balloon and releasing the payload from the balloon, then it has an 80 percent chance of effecting a successful air snatch and pulling the payload into the plane.
- About 10 percent of the time the balloon beacon and/or cutdown mechanism will fail and the balloon will pass through the network.
- There will be a small chance of recovering the payloads from the water or land if they pass through the recovery network or miss it entirely. This has not been considered, but might improve the overall recovery efficiency somewhat.
- The overall recovery factor for balloons which perform satisfactorily is 1.6, or, for example, 10 payloads recovered for every 16 which remain at altitude the required six to eight days.

These are the basic operational assumptions used to estimate the recovery effort. In Fig. 3 is shown the extent of the network, and the number of aircraft shown (a total of nine) represents the minimum which should patrol their respective sectors each operational day. The number begins to increase when the maximum expected on any one day exceeds about 45 balloons, and this occurs when the seasonal total of balloons launched exceeds about 2000.

The southern part of the network will have at least eleven to twelve hours of daylight each day at 20,000 ft, but the hours of daylight for the aircraft from Nome will vary from six to eight hours (in December) to about

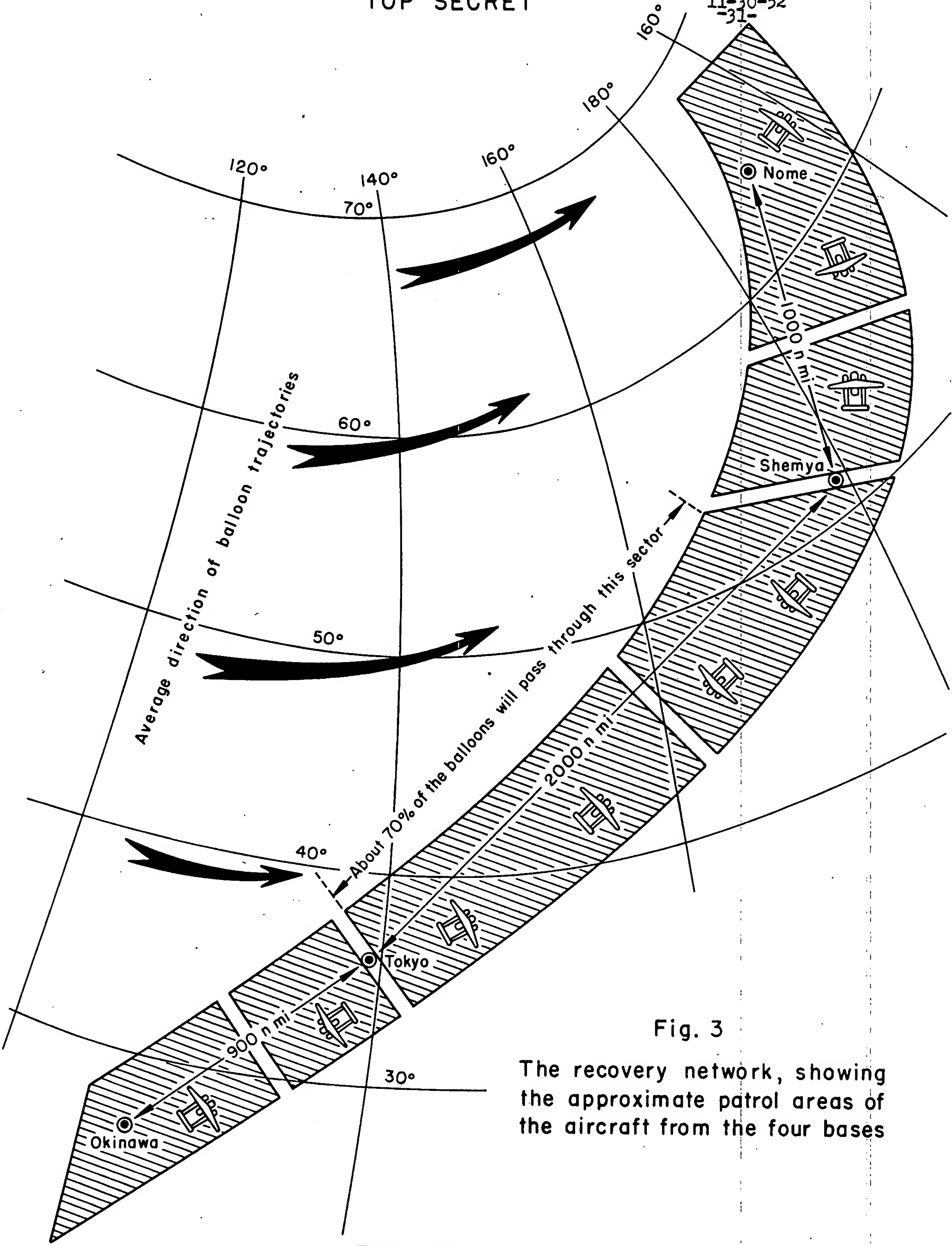

Fig. 3

The recovery network, showing the approximate patrol areas of the aircraft from the four bases

twelve hours (in March),* and so the time available each day will be more limited for the northern part.

The detailed flight patterns from the various bases have not yet been worked out. This will require some thought, in order to maximize the recovery efficiency for the distances to be flown each day.

3. The Balloon Tracking Problem

Balloons coming into a recovery sector in ones and twos must be detected and tracked by some long range ground DF network, which can then vector recovery aircraft to make an interception. This is the concept used in the limited and sporadic tests of Gopher balloons to date. However, as the flux of balloons increases it becomes necessary for aircraft to patrol a sector each day in order to be there when the balloons arrive, and the greater the flux of balloons the more aircraft must be used and the smaller the patrol sector of each aircraft. Thus, as the traffic becomes heavier the ground tracking and GCI control becomes less effective, but at the same time the area to be controlled by each aircraft becomes smaller. There will clearly be a point, then, when one should abandon GCI and adopt a "picket ship" system for intercepting the balloons.

It is not clear just where the transition from one philosophy to the other should take place, but provisions should be made for both the GCI and picket interceptions.

The GCI will require balloon-to-ground transmission over ranges of at

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* A. S. Mengel, "Hours of Darkness at Altitude," RAND Rept., RM-635, 1951 (Length of daylight based on time of sunset, considering direct sunlight being required for recovery operation.)

least 1000 mi to permit tracking, and this range should be attainable both day and night with something like 90 percent assurance. The present Stanley Aviation gondola has several HF transmitters, with an estimated power of 1 3/4 watts at each frequency. This has been shown to give reliably a readable signal to a ground station at 500 mi, using sky wave reflection. (Some five times more power would be required for ground wave reception.) If the transmitter were jacked up to 5 watts, a reliable range of 1000 to 2000 mi to a ground station could be obtained at night at the optimum frequency for sky wave transmission (the MUF), except in the auroral zone. During the day it may be necessary to raise the transmitted power in order to obtain the required 1000 mi range, since there is considerably more absorption of the sky wave during the day.

It should be emphasized, however, that the above power requirements to give the 1000 mi range are not definitely established, and must in all likelihood be determined by tests under operating conditions. There are many factors, such as the transmitter and antenna design (See Appendix A.), the signal-to-noise ratio required for the tracking, the design of the ground receiving antenna, etc., which must all be worked out together. The 5 watt and over power requirement set above seems too big in view of the occasional success of much smaller transmitters, but it must be remembered that sky wave transmission is extremely variable, and the long ranges which have been claimed for 1 and 2 watt transmitters do not represent reliable contacts.

The ground tracking stations will probably cost from $25,000 to $50,000 each, and a minimum of four will be required. The cost will depend to a large extent on the sort of antenna which will have to be used, and this will, in turn, depend on the signal strength to be expected. The communication

links and GCI center may have to be specially procured. For the present cost estimate, an outlay of $200,000 has been assumed for this entire facility, independent of the number of balloons involved. The specially trained personnel which would be required may number ten per station, or a total of about 40 men. The communications and GCI personnel should be added to these.

For the picket type of interception reliable air-to-air communication over about a 500 mi path will be required. This imposes several serious problems. First, this range is a little beyond line-of-sight, and so HF rather than VHF should probably be used. Optimum HF frequencies are in the 3 to 20 Mc band, depending on latitude, time of day, sunspot number, etc., and the standard Radio Compass AN/ARN-6 does not receive above 1.7 Mc. The power required is not established. For one thing, the minimum detectable signal aboard an aircraft is considerably larger than for a ground station, due to smaller and less directional antennas and a higher noise level. The power required for a 500 mi air-to-air transmission will probably have to be established by actual tests.

Since all the payloads will not be recovered by the air-snatch, for one reason or another, some provisions have been made in the present gondola for recovery from the surface. The VHF transmitter will continue to operate after landing, and provisions will be made for a dye marker and for floatation. In addition, the top side of the gondola should be brightly painted with red or orange fluourescent paint to aid in the detection of the gondola in the water. With these precautions, plus a notification to surface craft of the location of the packages (when this is known), there should be a fair

chance of recovering those which are missed by the recovery aircraft. This is further enhanced by the fact that a certain percentage of the gondolas that fall into the sea will come down within the well traveled Pacific sea lanes.

E. Trajectories and Coverage

It should be stated at the outset that practically no data are available on trajectories over Eurasia at 60,000 to 70,000 ft or above. It is necessary to estimate what a family of wintertime trajectories at this altitude will look like from upper air synoptic charts prepared for lower altitudes (below 55,000 ft) and for the North American Continent. The maximum altitude for which we have any significant data over Eurasia is about 40,000 ft (200 mb). Nevertheless, there is every reason to believe that the winds used in the calculations below will generally be representative of conditions at the Gopher altitudes.

1. Coverage

As in the original RAND study, a point on the ground is considered "covered" if a photograph is obtained of it from a balloon at a reasonable range. The first approach to determining the fraction of points in a given section of Russia which would be covered is to consider the coverage by a given number of "effective balloons" launched from a given point upwind. An effective balloon, as the name implies, is an idealized balloon which takes pictures day and night, regardless of clouds, and covers a strip 30 miles on either side of its path.* (The original RAND study assumed only

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* The Beacon Hill Report indicated that a 3 in. focal length camera at about 60,000 feet could detect large-scale man-made features such as airfields, railroads, dams, factories, etc., at 30 mi horizontal range and over. A brief study at RAND of high altitude pictures has confirmed this contention.

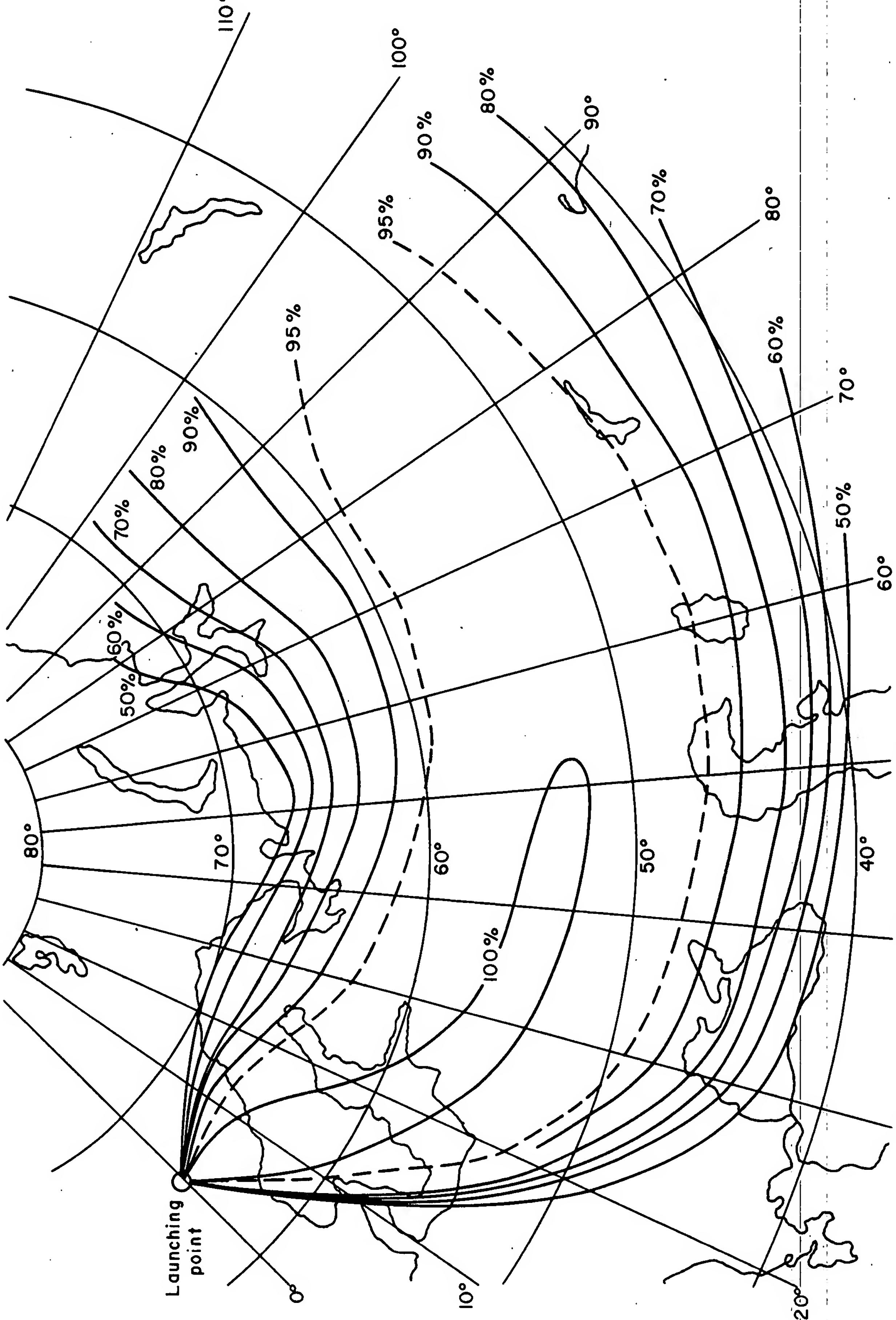

Fig. 4 —— Coverage by 100 effective balloons

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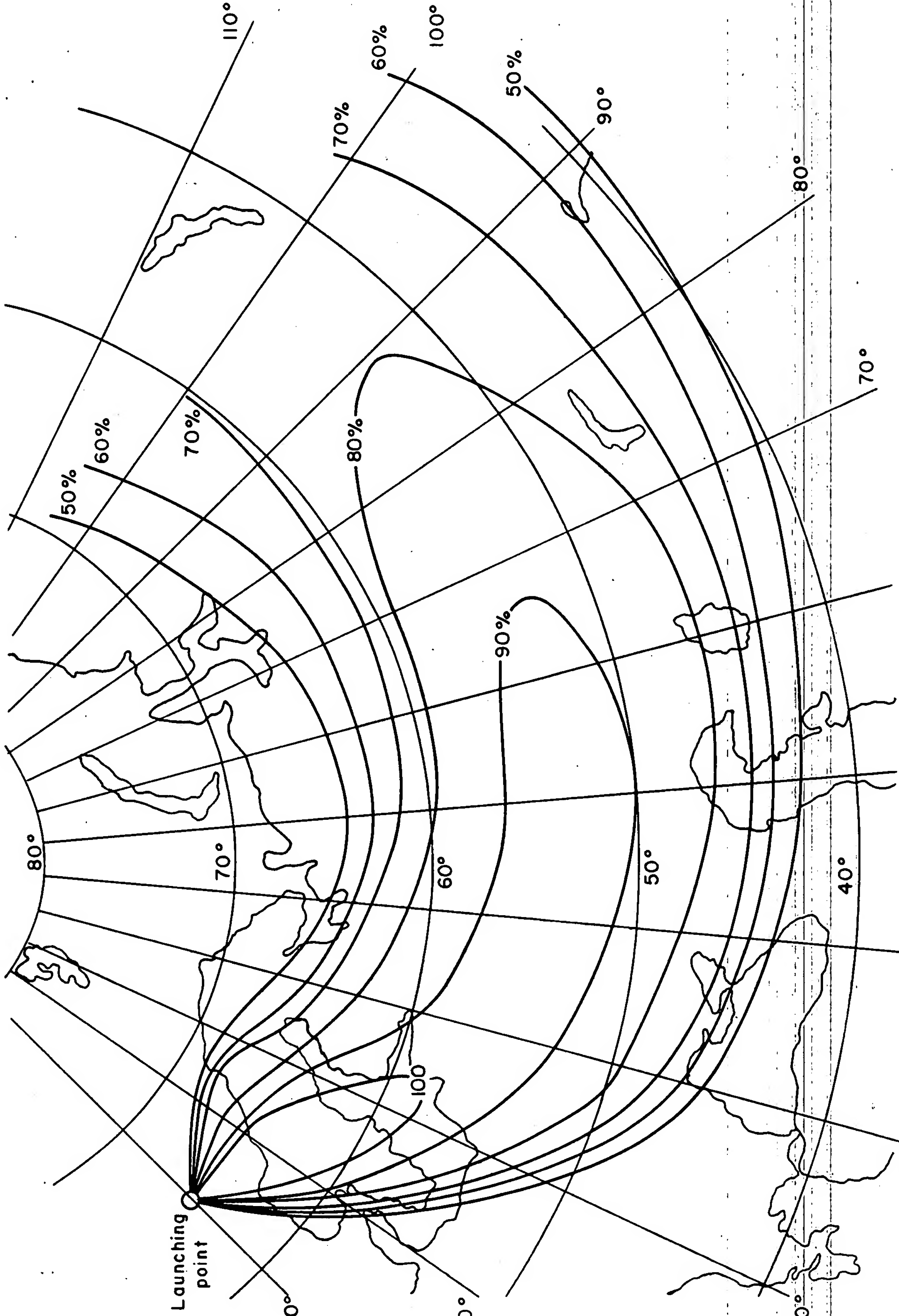

Fig. 5 —— Coverage by 50 effective balloons

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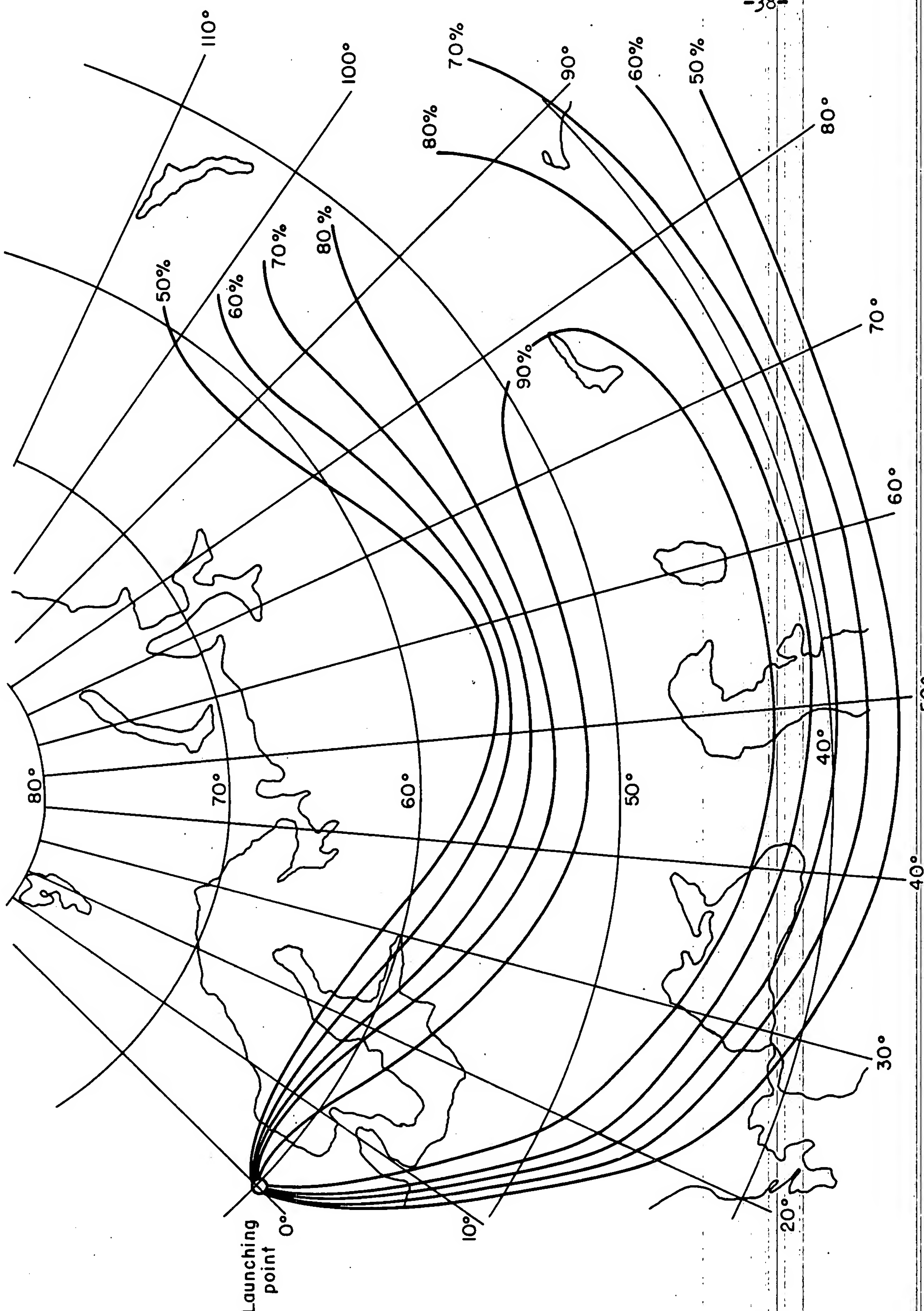

Fig. 6 —— Coverage by 50 effective balloons

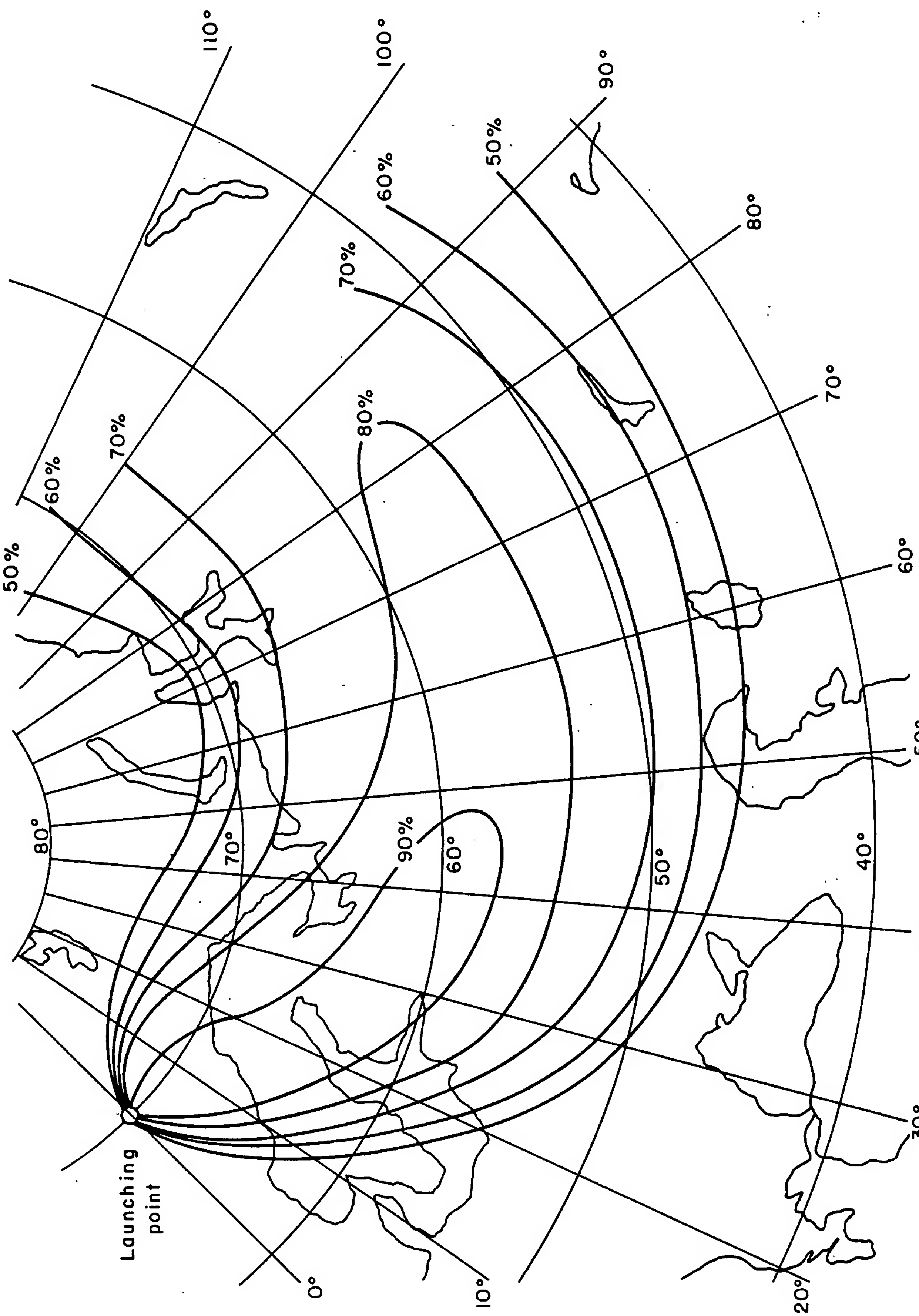

Fig. 7 — Coverage by 50 effective balloons

15 mi on each side.)

Figs. 4, 5, 6, and 7 show the coverage patterns for various numbers of effective balloons and launching points. Appendix D explains in more detail how these were calculated.

It is now necessary to determine the actual number of balloons which would give the same coverage as a given number of effective balloons. In order to do this, "degredation factors" for darkness, cloudiness, and failure to recover must be derived, and these will, in general, also be functions of geographical position.

The factors for darkness and cloudiness are shown in Fig. 8. The darkness factors are just the ratio of the whole day (24 hours) to the hours of daylight at the ground, and they are shown for January 15, the middle of the operation period. They will be less favorable in December and more favorable in February and March. The cloudiness factors are the average number of days one would have to wait in winter in order to get a day with 3-tenths or less cloud cover, and are based on an Air Weather Service study.* Using mean factors for an entire region is clearly over-simplifying the problem, but is justifiable here because it is mean coverage that is desired as the end product.

The overall recovery factor, including the balloon performance, performance of the gondola components, and success of the recovery operation (See Section D.) is probably about two. Actually, it would be a little

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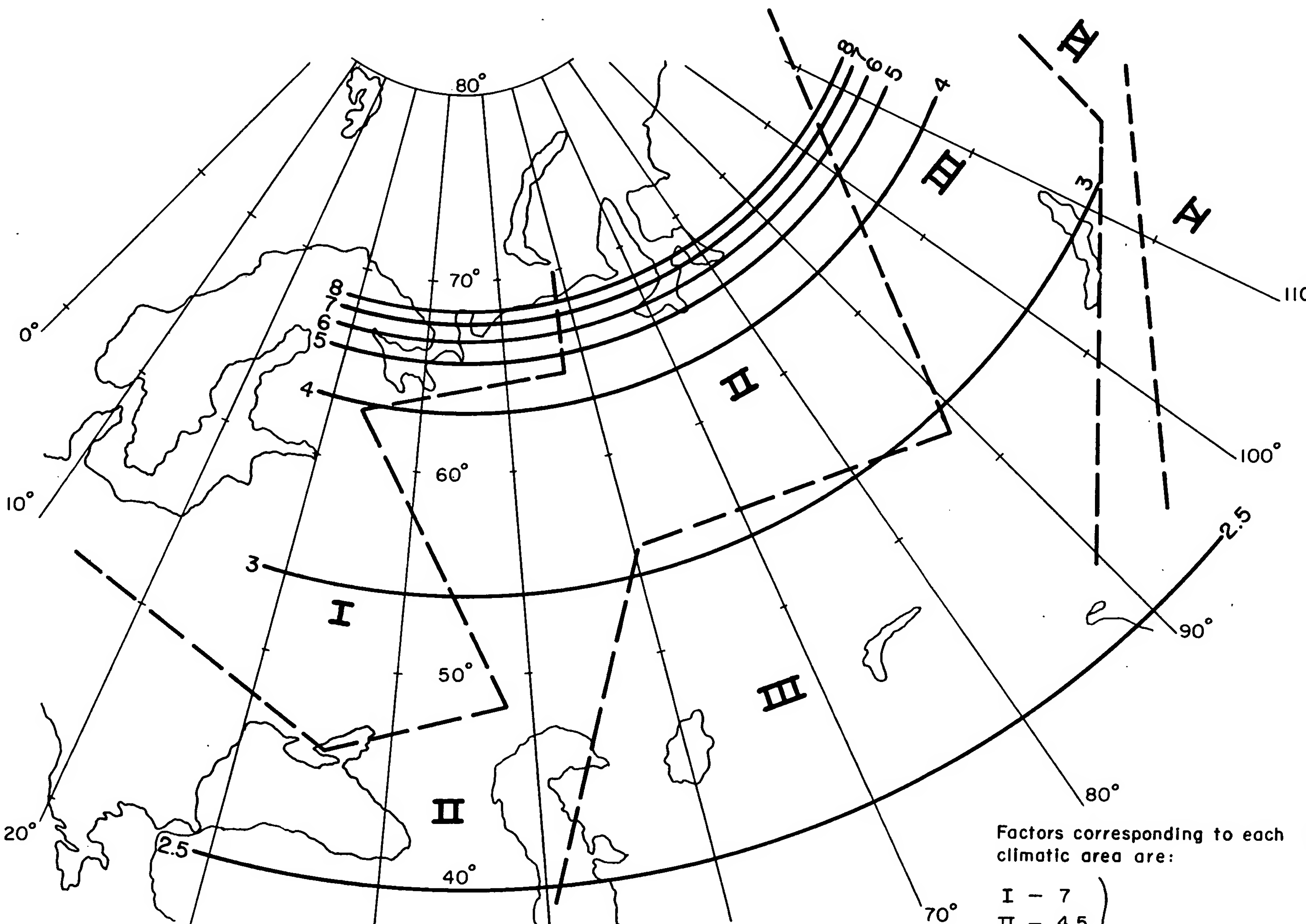
* "Areal and Altitudinal Variations of Cloud Conditions Favorable for Visual Photo-Reconnaissance Operations Over Eurasia," Directorate of Climatology, Hqs, Air Weather Service, October, 1952 (SECRET).



Factors corresponding to each climatic area are:

I — 7
II — 4.5
III — 3
IV — 2

cloudiness factors

Fig. 8 — Degradation factors due to darkness and cloudiness

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larger in the northern part, where recovery is more difficult, and smaller in the south, but this elaboration was not considered in the calculations.

The average coverage for all of Russia west of Long. 100° E can now be estimated as a function of the actual number of balloons launched.* This average coverage is defined as an area integral or summation:

$$C_{Ave}(n) = \frac{\sum_{Area} C(n) \; \triangle(Area)}{Total\ Area}$$

where $C(n)$ is the coverage of a given element of area, $\triangle(Area)$, by n actual balloons. This process is described in Appendix D, and some more detailed results are given there.

Fig. 1 shows the results of this calculation. It is interesting to note how rapidly the average coverage increases for the first few thousand balloons, and how little additional coverage is obtained by a further increase. However, since it is a random process, it may require a relatively high coverage before we can rest assured that we have not missed an important installation. It is likely that the coverage shown here would apply fairly well to all of Russia, including the part east of Long. 100° E, since the trajectories continue across the area in a west-east direction. It is also possible that the coverage would be slightly improved by optimizing the launching site, or by the use of multiple launching sites, though this is questionable in view of the large dispersion of the balloons from one site and the likelihood that

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* The Gopher reconnaissance system is, by its very nature, a random process, and should only be considered as a <u>pioneer reconnaissance</u> system. It would be possible in principle to optimize the coverage of a particular part of Russia, but it is generally felt that doing so would defeat the chief virtue of the system, which is its wide and wholesale coverage. The coverage is therefore calculated for <u>all of Russia</u>, with no weighting factors assigned to any particular areas.

there will be a year-to-year variation in the pattern which would be difficult to predict.

2. Distribution of Balloons in the Recovery Network

Clearly, in order for a balloon to be recovered it must emerge from enemy territory within a reasonable time and in a favorable place. Theoretical trajectory calculations can throw considerable light on this matter. An Air Weather Service study based on 200 mb synoptic charts gives the distribution of calculated trajectories originating at Lat. 59°N, Long. 3°E, as they cross the 150°E meridian, which is approximately the recovery area.* This distribution is shown in the table below.

Latitude	Percent of Trajectories crossing the 150°E Meridian in a Given 5° Interval
80°N	
	3.1
75	
	2.7
70	
	4.0
65	
	4.0
60	
	5.4
55	
	12.1
50	
	22.9
45	
	29.1
40	
	20.6
35	
	15.3
30	
	5.0
25	
	0
20	

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* "Upper-Air Trajectories Over Europe and Asia," Directorate of Scientific Services, Hqs, Air Weather Service, April, 1951 (TOP SECRET).

Another significant result of this study was the finding that the median time of the flights was 5 1/4 days, with about 70 percent of the hypothetical balloons completing it in 6 days and over 90 percent in 7 days. Some balloons would have required only slightly more than three days. These short times may be optimistic, since they were calculated for about 40,000 feet (200 mb), where winds are probably somewhat stronger than at the proposed flight altitudes. (See Fig. 9.)

The conclusions to be drawn from these results are:

- The recovery network need not extend south of about 20° Lat.
- Roughly one-third of the balloons will be carried into the region of the Aleution Islands and the Bearing Sea, so every attempt should be made to extend the recovery network into this inclement area and to develop all-weather techniques for recovery, such as the air-snatch.
- In winter about 90 percent of the balloons will complete their trip over Asia in less than 7 days. Any additional duration which could be built into the balloon would increase the number recovered and would lengthen the season during which the system could operate.
- If the northern part of the recovery network can be maintained, then <u>about 90 percent of the balloons which manage to stay aloft for up to 8 days will enter the recovery network</u>, which is assumed to extend along the

western edge of the Pacific from about 20°N to 70°N. (See Fig. 3 . Some 5 percent will be lost still farther north over the Arctic Ocean. The recovery network could conceivably cover this area, but it would not appear to be worth the large effort to recover such a small fraction.)

o The best launching point, as indicated in the previous section, will be the North Sea or Northwestern Europe between latitudes 60° and 70°N.

3. Winter and Summer Winds in the Stratosphere

It is common knowledge now that a reversal in the stratosphere winds takes place between winter and summer. The question is frequently asked: Why not operate our balloons in summer from east to west? Would it not be easier this way, due to the longer daylight and the better weather at the surface? The purpose of this section is to briefly summarize what appears to be the prevailing stratospheric wind pattern, even though there are not enough data to be very certain about the details of it, in order to provide an answer to these questions. What follows is pieced together from several sources, and cannot all be found in the literature.

In Fig. 9 is shown the approximate distribution of the mean zonal (east-west) component of the wind in summer and winter as a function of latitude and altitude. There will be some variation with longitude, but the fact that these were based on observations over the North American Continent suggests that they may be fairly representative of conditions over the Eurasian Continent.

It is necessary to qualify the mean picture shown here by some further statements about the daily variations from the mean. First, it is well known

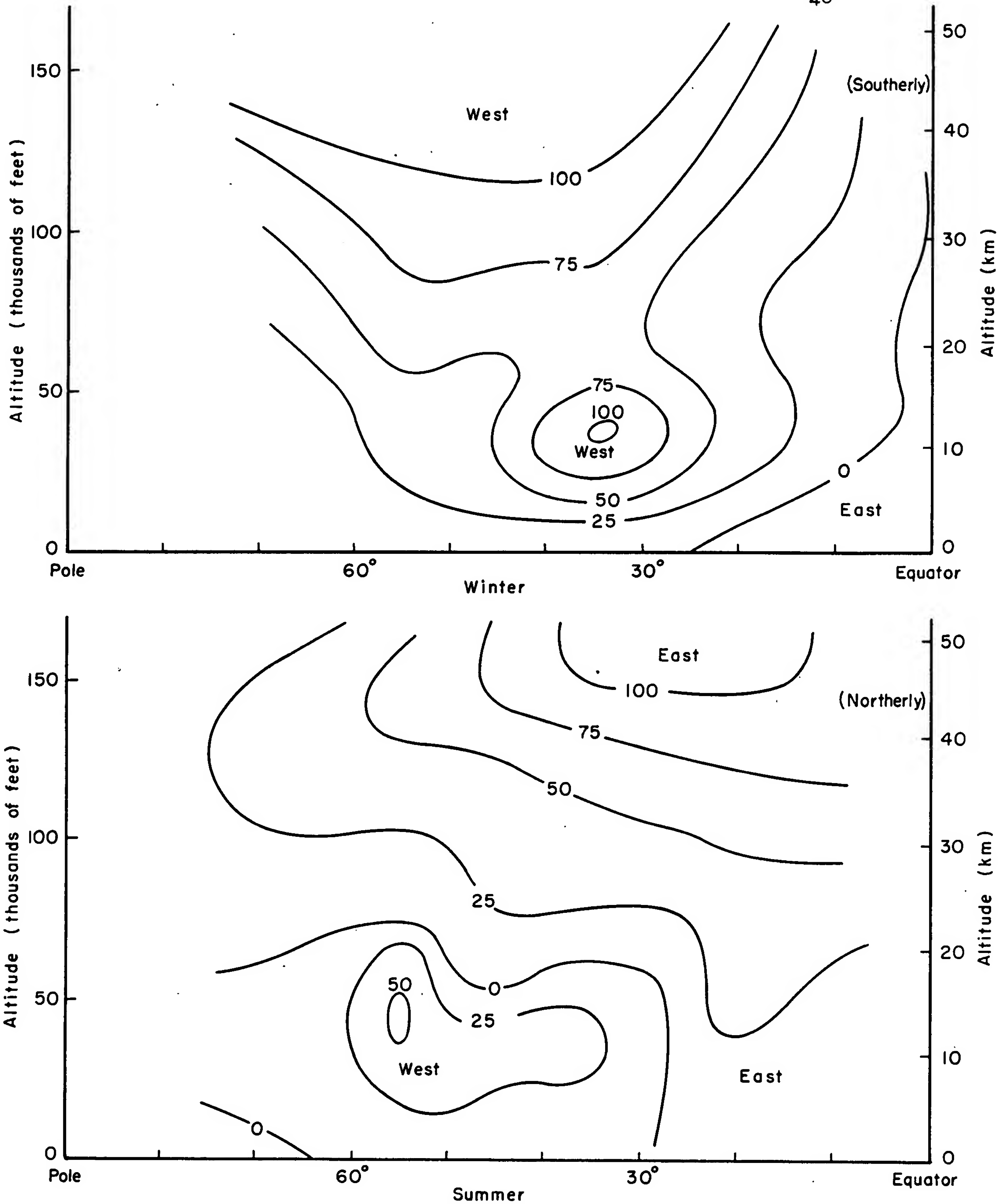

Fig. 9 — Mean zonal winds in the stratosphere (knots) over the North American continent

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that the winter maximum at around 35,000 ft and latitude 35°, the so-called "jet stream," moves up and down and north and south. So, indeed, do all the features of these mean cross sections.

The region of transition from lower westerlies to upper easterlies in summer, between about 50,000 and 70,000 feet, actually is a region of light variable winds, with relatively large north-south components, and sometimes with closed circulation systems, particularly in the southern part.

It is not until one reaches an altitude of 70,000 to 80,000 feet in summer that the east winds at middle latitudes become at all consistent, and then they appear to increase with altitude. Thus, in order to conduct a Gopher operation with any success in summer, one would have to operate above 70,000 to 80,000 feet, and the balloons would have to have greater endurance in order to make up for the general weakness of the east winds. Our present balloons do not quite provide such performance, but they may in the future. (See Appendix B.1.6.) Thus, there is a good possibility for eventually carrying out a summertime Gopher operation.

References and Sources of Information on Stratosphere Winds:

1. Brasefield, C. J., "Winds and Temperature in the Lower Stratosphere," Jour. Met., Vol. 7, pp 66-69, 1950.

2. Crary, A. P., "Stratosphere Winds and Temperatures from Acoustical Propagation Studies," Jour. Met., Vol. 7, pp 233-242, 1950.

3. Crary, A. P., "Stratosphere Winds and Temperatures in Low Latitudes from Acoustical Propagation Studies," Jour. Met., Vol. 9, pp 93-109, 1952.

4. Gildenburg, B. D., Research Meteorologist, E and A, Holloman AFB, unpublished data.

5. Kellogg, W. W., and G. F. Schilling, "A Proposed Model of the Circulation in the Upper Atmosphere," Jour. Met., Vol. 8, pp 222-230, 1951.

6. Kellogg, W. W., "Temperatures and Motions of the Upper Atmosphere," Chapt. IV in: Physics and Medicine of the Upper Atmosphere, University of New Mexico Press, 1952.

7. Mantis, Homer, Assistant Professor, University of Minnesota, unpublished data.

8. Rossby, C. G., "On the Nature of the General Circulation of the Lower Atmosphere," Chapt. II in: The Atmospheres of the Earth and Planets, University of Chicago Press, 1949. (Data on mean winds were prepared by Seymour L. Hess for this paper.)

9. Willett, H. C., "Descriptive Meteorology," Academic Press, N.Y.C., 1944.

III. Campaign Costs

In the preceding chapter the balloon reconnaissance system was described in some detail, component by component. It is now necessary to combine all the components and to determine what would be required for a given number of balloon launchings. The basic campaign assumptions have already been made, so the process of adding up costs contributes relatively little to an understanding of the system.

It should be emphasized that the costs which will be considered here will only be the explicit costs of the expendible gear, the specially procured ground equipment, and the costs of operating the recovery aircraft. Actually, the total cost to the Department of Defense will be much more, since there will be an extensive training program (as indicated by the number of specially trained personnel), recovery aircraft and launching facilities to allocate and maintain, and the cost of transporting such a complex task force. These are not included in the dollar costing, but are indicated in the calculations and should be kept in mind when contemplating the level of effort required to mount a campaign of a given size.

Requirements for a campaign are given in the following table. Detailed explanations of how these were estimated are usually to be found in the preceding chapter, but the "ground rules" for the campaign are briefly summarized below for convenience. The results are also shown in Fig. 2 .

TABLE OF
CAMPAIGN REQUIREMENTS

Requirements	Total Number of Balloons Launched in a Season				
	1,000	2,000	4,000	6,000	10,000
1. Balloons launched each day favorable for launching	20	40	80	120	200
2. Balloons launched per hour on favorable day	2	4	8	12	20
3. Number of launching crews and associated launching gear required	1	2	4	6	10
4. Gas used each day favorable for launching (millions of ft^3)	.4	.8	1.6	2.4	4
5. Gas generating capacity required for a carrier (thousands of ft^3 per hr)	20	40	80	120	200
6. Cost of hydrogen procured commercially and transported to launching site (millions of dollars)	.1	.2	.4	.6	1
7. Recovery aircraft which must be in the air each day when weather permits	9	9	16	25	40
8. Total force of recovery aircraft	17	17	28	40	70
9. Approximate total number of flying hours spent on recovery missions	810	810	1440	2160	3600
10. Cost of operating and maintaining the aircraft (millions of dollars)	4.0	4.0	7.2	10.8	18.0

11. Total explicit cost of non-expendible equipment and operation of recovery aircraft (millions of dollars)	4.5	4.6	8.0	11.7	19.3
12. Cost of balloon and associated expendible gear (millions of dollars)	8.35	16.7	33.4	50	83.5
13. Total explicit cost (millions of dollars)	13	21	41	62	103
14. Number of specially trained personnel for launching, tracking and recovery	148	154	232	316	520

SUMMARY OF RULES FOR

CALCULATING THE CAMPAIGN REQUIREMENTS

Item 1. o The length of the season with favorable winds in the stratosphere is 100 days.

o For a carrier launching base, 50 percent of the days in the northeast Atlantic will have winds less than 20 knots, so a "no wind condition" can be obtained for launching.*

o For a land base, 50 percent of the days are favorable for launching (limiting conditions have actually not been determined).

Item 2. o Ten hours, on the average, are available for launching on each "favorable day." This takes into account the usually large diurnal change in wind at a land base, and the time required to steam back upwind in the case of a carrier base.

Item 3. o It takes a four-man crew one-half an hour to inflate and launch a balloon.

o It takes two men the same length of time to ready the associated gear and move it to the launching site.

Item 4. o Each balloon requires about 20,000 ft^3 of hydrogen (or helium).

Item 5. o A carrier (or seaplane tender) can store up to 2 million ft^3 on its hangerdeck, about the equivalent of the gas capacity of 10 railway tank cars or 60 truck trailers,

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* "Atlas of Climatic Charts of the Oceans," U. S. Wea. Bu. Rept. No. 1247, 1938.

plus the compressors. This much will actually not be required, unless the generator breaks down.

- o The hydrogen generator can run twenty hours each day, and will be able to supply enough to launch balloons at the daily launching rate for an indefinite time.
- o In terms of industrial generating plants, this gas generation requirement is reasonable, but the cost of procuring and installing a plant in a vessel may be quite large. It is assumed for the sake of this estimate that the cost of the plant will range from .5 to 1 million dollars.

Item 6. o The cost of hydrogen at an industrial plant is less than \$.50 per 1000 ft^3. Delivered in tanks, in the U.S., it runs from \$7.50 to \$22 per 1000 ft^3.* It has been assumed here that it would cost \$5 per 1000 ft^3 delivered to the launching site, or \$100 per inflation.

Item 7. o For low balloon densities an aircraft patrols a 500 mi sector, as shown in Fig. 3 .

- o As the daily balloon density (equal to daily launching rate) increases, the number of aircraft is increased to keep an average of five recoveries per aircraft per day. (See Section II. D.)

Item 8. o Abort rates, etc., are the same as for bombing campaigns. (See Section II. D.)

- o One standby aircraft is kept at each base to supplement every five operational aircraft.

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* "Lifting Gas Requirements of a Balloon Delivery System," J. R. Smith, General Mills, Inc., Rept. No. 1073, 21 March 1952.

- There are four bases of operation.

Item 9.
- Each operational aircraft flies, on the average, a daily ten hour mission.
- The operation lasts for 100 days.
- 10 percent of the time weather grounds the aircraft, an average for the network.

Item 10.
- Fuel, oil, maintenance, and depreciation of the aircraft cost about $500 for each flying hour.

Item 11.
- The launching facilities cost about $20,000 per launching crew for the land base, and about $1000 per crew on the carrier (since the latter always launches in a "no wind condition").
- The increased cost of the gas generation and storage more than offsets the lower launching equipment cost on the carrier, making the total sea launching cost slightly more. The figure given is the average between the sea and land based systems.
- The DF tracking network costs about $200,000, independent of the number of balloons launched.

Item 12.
- Each complete set of flying gear costs about $8350.
- None is recovered in time to be used over again in one season's operation.

Item 13.
- Sum of 11 and 12.

Item 14.
- Four men per launching crew for balloon.
- Two men per launching crew for reading the gondola.
- Ten men per DF tracking station, and four stations.

o Six trained men on each recovery aircraft, and the same number of crews as total aircraft. (See Section II. D.)

IV. TECHNICAL PROBLEMS REMAINING

A. Recovery

The recovery operation requires in particular the development and procurement of the following items of hardware:

- o A winch with the proper power and braking controls for the recovery aircraft. Also, a suitable auxiliary hoist for lifting the heavy (300 to 400 lb) package into the plane after it is reeled in. (See Appendix C.)
- o A stable, light weight, reinforced parachute to meet the requirements of the air-snatch maneuver.
- o Suitable DF equipment for the recovery aircraft. Possibly the standard Radio Compass, ARN-6, could be modified to cover the high frequency band from 1.7 to 20 Mc. (See Section II. D.)
- o An improvement in the balloon HF transmitter, to provide at least 1000 mile range to the ground receiving stations during the day, and more than this at night. (See Section II. D.) This will mean about 5 effective watts or more instead of the present 1 3/4 watts, and will be at a frequency in the 3 to 20 Mc range. (There is some controversy about the power and frequencies required for a reliable daytime air-to-ground 1000 mi range, and an important part of the program should be to determine realistic requirements. If the power requirement turns out to more than 5 or 10 effective watts, then the recovery requirements may have to be revised to provide a more dense network of

ground or shipborne radio stations, since it will probably not be possible to provide enough power in the balloon for a transmitter of more output than this.)

B. Balloons

- Adequate duration can be achieved by using balloons which have already been demonstrated in the field, incorporating such recent improvements as the laminated polyethylene film, the heat sealed top, the University of Minnesota Appendix, etc., and relatively conventional constant altitude ballast controls. (See Section II. C. and Appendix B.) Any further refinements in the vehicle and its altitude control will improve the duration and the reliability of the system, and so research in this direction should continue.
- Launching techniques for a land base should be perfected which will ensure a successful operation over 50 percent of the time in winter. This will clearly vary from place to place, but a perusal of wind frequencies for the U.S.* indicates that this requirement would be met by a system which could cope with maximum winds during the launching of 15 knots, accompanied by a mean wind which would be a few knots less. The General Mills reefing tube may provide a solution when no weighing off is required, but this should be more extensively tested, along with other proposed schemes. (See Appendix B.)

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* "Airway Meteorological Atlas for the United States," U.S. Weather Bureau Rept. No. 1314, 1941.

C. Cameras

A lightweight special camera should be designed for this purpose, incorporating the ingenious features of the present modified K-17 camera as developed by Stanley Aviation, which includes data on time, altitude, solar angle, and tilt directly on the aerial photo. In order to provide the best coverage with a reasonable size of film and a 3 or 6 in. lens, a multi-camera arrangement appears to be the best, since this would eliminate the requirement for rotation of the gondola. (See Section II. A.)

D. Test of Vulnerability

A number of considerations depend on determining the probability that the enemy can shoot these balloons down at a given altitude. Since this is a very complex problem, it is probably necessary to determine the detectibility and vulnerability of the balloon and payload by actually conducting a small scale field problem over the U.S., using the best equipment available to our forces to try to detect and destroy a few balloons. This has already been proposed to the Air Force, and a program is underway.

APPENDIX A

METHODS FOR REDUCING DETECTIBILITY OF THE BALLOON AND GONDOLA

1. Methods for Reducing the Radar Cross Section

The balloon itself will be the most visible part of the Gopher assembly, but for a radar the gondola and its antennas will be the part which is detected. The present Stanley Aviation Company gondola is a rectangular box roughly 2 by 2 by 3 ft. Since it is covered with aluminum foil for insulation, it can be considered as a good conductor. Appendages are, at present, a trailing wire 85 ft long for the HF antenna, and a short vertical whip VHF antenna cut for 150.12 Mc. The load lines, parachute risers, etc., are usually nylon, and will add little to the radar cross section.

Intelligence on Russian radars is probably incomplete, but it is known that they have VHF radars in the general range of frequencies between 55 and 240 Mc. They also have microwave radars similar to our early warning and tracking sets. The radar cross section of an object such as the Gopher assembly is a function of wavelength, aspect, and polarization of the radar wave, so it will not be possible to specify how well the vehicle will be seen. There are a few general factors, however, which should be kept in mind.

If the ground radar is a VHF radar with a wavelength more than twice the width of the gondola (or less than about 150 Mc), it will not see the gondola with horizontal polarization. The gondola can be thought of as a broad-band antenna with a maximum horizontal length of between 2 and 3 ft (depending on its orientation), and such an antenna will not be very effective if it is shorter than a half wavelength, or dipole.

If the radar uses a vertically polarized beam, however, the various vertical antennas on the gondola will be quite good targets, since they are long enough to provide some resonance at all VHF frequencies. In particular, there is a German type radar at 150 Mc, called the "Freia," which is known to use vertical antenna elements, and this radar would probably see the 150.12 Mc VHF beacon whip antenna as a tuned dipole, which would provide a good return. It is not known how many of these the Russians may be using.

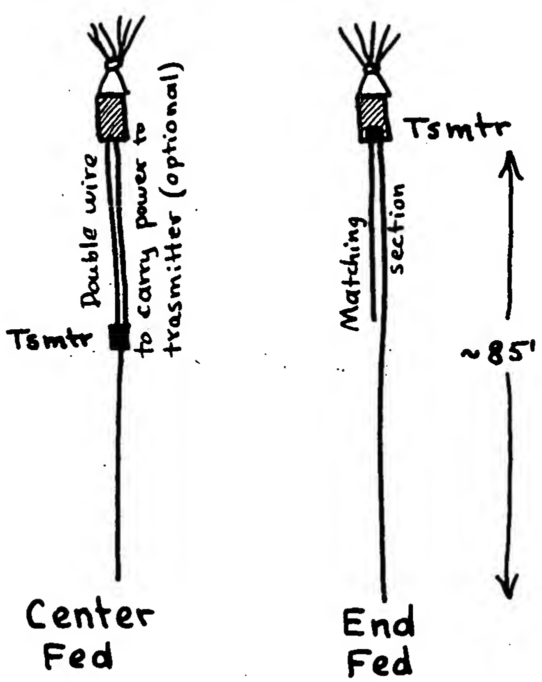
The cross section of the gondola and antennas for microwave radars is probably small relative to, for example, a bomber aircraft, since it presents a small total area. (The ratio of the areas of a B-47 and a Gopher vehicle is about 100:1.) This has been borne out in U. S. tests, where ground S-band radars have generally had difficulty acquiring the high altitude "skyhook" balloons, with trailing antennas, and have usually succeeded in tracking them to only limited ranges. One difficulty with microwave early warning sets is the vertical restriction of their antenna beam. Being designed for detecting aircraft flying at 20,000 to 30,000 ft, they do not have much return from a target flying at 60,000 ft unless their antennas are tipped upwards especially for this purpose. This is possible, in principle, if they are to be used for balloon tracking.

The return from the Gopher assembly may be enough for an airborne radar to see it at limited ranges. The broadside cross section, as seen from an aircraft flying at the same altitude, will be considerably larger than that seen from the ground, but for an aircraft flying below the balloon the ranges may be expected to be only two to five miles. This is not enough for an interception without GCI.

The most effective ground radar for tracking the balloons will therefore be the VHF radars with vertical polarization, so it is against these primarily that the balloon must be "camouflaged." The following discussion deals with this particular problem.

The obvious way to reduce the radar cross section is to eliminate or retract the antennas, since these provide most of the echoing area. This is particularly true of the 150.12 Mc antenna, which will provide a strong signal. This antenna could be stowed directly against the side of the gondola during its transit across the enemy territory, and then swung out away from the gondola when needed for transmission. The present long trailing wire would have to be let down by a reel, which would probably be fairly simple to arrange.

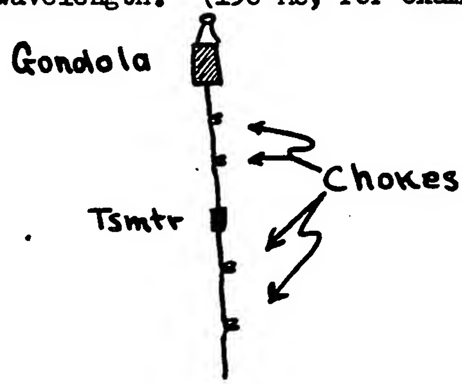
A better way to arrange the HF transmitter may be to have it hung at the midpoint of the antenna. An experiment by General Mills has indicated



that this center fed antenna gives in the order of 20 db improvement in signal strength over the end fed antenna with a matching section at the upper end. If this is verified by further tests, then the center fed arrangement should probably be adopted, but then the lowering of the transmitter plus antenna becomes somewhat more complicated. Before the transmitter is scheduled to go on the air a reel would have to be released to lower the transmitter on its antenna wire, and at the same time another reel would have

to be released from the bottom of the transmitter to lower the rest of the antenna. This is feasible in principle, but represents another possible source for failure due to component malfunction.

An alternative and simpler way of reducing the HF radar cross section would be to cut the antenna up into smaller elements, each element isolated from the other by an rf choke coil which would pass the HF signals but would represent a large impedance to the VHF radar frequency. In this way, the radar wave would reflect from a large number of small sections of wire, each section being less than one wavelength but not any simple fraction of a wavelength. (150 Mc, for example, corresponds to a wavelength of 2 m.)



Before such a system could be used it would be necessary to find out what VHF frequencies were being used, since, if the segments happened to be cut to the wrong size, they might turn out to be tuned elements and would add instead of subtract from the radar cross section. These rf choke coils would add to the weight of the antenna, but could probably be constructed light enough to avoid excessive weight. It might be that the weight of the choke coils would only be comparable to the weight of retracting reels and switches, and their use would probably make retraction unnecessary. Their greater simplicity might then make the choke coil system for reducing the radar cross section preferable.

Since there are so many factors involved, it is clear that this question should be studied in more detail, with reference particularly to what ground radar sets the Russians may have available. It may be advisable to fly a

few balloons specially instrumented to record or relay enemy radar signals for ECM analysis. (This is the subject of a separate study in progress at RAND.)

The choke coils would not significantly reduce the radar cross section for an airborne microwave set carried to balloon altitude, since each segment of antenna would still provide a good signal in the horizontal plane. However, if the ground tracking network was rendered useless, then GCI would not be possible and the aerial interception would be quite difficult without a large patrol effort. It is doubtful that aerial interception will be possible anyway at the altitude of the balloons. The primary weapon would probably be guided missiles or barrage rockets (see Section II. B. 2), and these depend on ground tracking.

2. <u>Methods for Preventing the Balloon Borne Radio Beacon from Being Prematurely Activated</u>

After about three days it is planned to turn on the HF beacon, since this is about the minimum time for a balloon to reach the recovery network. Some slower balloons will still be over the middle of enemy territory, however, and it will be very easy for the Russians to track them by DF methods. Since this is an undesirable situation, it would be much better to have the beacons turned on when they cross a certain meridian of longitude or enter the recovery network.

There are a few proposed methods for doing this:

- Only activate a <u>receiver</u> at the end of three days, and then have the beacons turned on at a command from the recovery network.

  <u>Comments</u>: The command signal can be heard by the

Russians, and they could then duplicate it and activate the beacons prematurely.

- Provide a time-of-sunrise sensing device, which would turn on the beacon when a sunrise occured before a certain GMT. (Lines of equal time-of-sunrise run roughly parallel to the recovery network in winter.)

  Comments: An error or delay of nearly a whole day could occur, since only one observation per day is possible. For a fast moving balloon this may amount to as much as 2000 mi or more, but this is still a great improvement over the fixed time method. Equipment to do this is partly developed, and is relatively simple.

- Provide a time-of-maximum-solar-elevation sensing device, which would turn on the beacon when the subsolar meridian was passed before a certan GMT.

  Comments: The meridians of longitude do not run parallel to the recovery network, so some balloons to the north, over Siberia, would have to turn on their beacons too early in their travel. There is also a possible error of 2000 mi because of taking only one observation per day. Equipment to do this is partly developed, and would be more complex than that required for the time-of-sunrise device.

- Provide an angle-of-magnetic-declination sensing device, involving the comparision of a magnetic and a semi-constrained north-seeking gyro compass. As the balloon travels

eastward the magnetic compass will continue to seek the magnetic pole, while the gyro compass, constrained in one direction, will line itself up with the earth's axis and show true north. At the launching area the magnetic compass will point to the west of the gyro compass (a west declination), but about as the balloon enters Russia the declination will shift to an east declination, and remain there until it reaches Central Asia, at between 100° and 120°E longitude. It will then observe a west declination until between 150° and 165°E longitude. If a programming device were set to observe the sequence of shifts from west to east to west to east and then activate the beacon, the beacon would come on somewhere between about 150° and 165°E longitude, depending on the latitude of its flight.

Comments: The region at which it turns on the beacon is too far east to be of use to the Okinawa-Tokyo-Shemya-Nome network, as described elsewhere (see Section II. D.). However, an alternate line of recovery bases could be Kwajalein-Wake-Midway-Shemya-Nome, and this mid-Pacific line would be in a good position to track and recover these balloons. There is a possibility that a balloon would have a distorted trajectory which would lead it back and forth and cause it to pass through the sequence of declination changes prematurely. However, such a trajectory is quite unlikely during the winter, when the zonal flow is steady. Also,

there are a few strong magnetic anomalies, such as the one near Kursk (51° 15' N, 37° 30' E), which might confuse the sequence. These are local singularities in the magnetic field, however, and would only be expected to confuse a few of the balloons which happened to pass directly over them. Their effect decreases with altitude, so anomalies which caused a reversal in declination at the ground would not necessarily cause a reversal at 60,000 ft above the ground. The equipment to do this would have to be developed, but should be reasonably simple. Errors in declination measurement of two or three degrees could be tolerated.

Appendix B

The Balloon Problem

1. The Balloon

A. Requirements of the Gopher System

As stated in the section on balloons (Section II. C.), the vehicle has been developed to the point where it can now accomplish the required task. It should be noted for the record, however, that the requirements as originally set forth were modified at several points by the Air Force in an intelligent effort to bring the program into line with practical possibilities. The present requirements are as follows:

	From original RAND Report*	Present Requirements Day	Present Requirements Night
Floating Altitude	60,000 ft	58,000 ft	45,000 ft
Duration of Flight	6 days	6 - 8 days	
Gross Payload	~1000-1500 lbs	1500 lbs	
Gondola Weight	500-600 lbs	350-450 lbs (Any savings to be used as ballast)	
Balloon Diameter	100 ft	73 ft	

(* The requirements as set forth in RM-494 are included for comparison purposes only.)

The above requirements determine the limits imposed on the balloon. The flight test results indicate whether these requirements have been accomplished or are feasible in the near future.

B. Weight of the System

Details of the construction and characteristics of the polyethylene balloons used on the Gopher Project are given in the General Mills Inc. Final

Report (dated Sept. 1952). It is constructed of about 2 mil polyethylene film (sometimes laminated) heat sealed between gores, and with plastic tape glued over each seal. These plastic tapes pass over the top and also extend below the balloon, serving as load lines to support the gondola. A 2 mil, 73 ft diameter (approximate), balloon weighs about 230 lbs, of which about 25 percent is due to the tapes.

As stated in Section II. A., the early version of the gondola weighs about 460 lbs, but this can certainly be reduced to 400 lbs or less in production models, to which must be added some weight for lines, parachutes, etc. For a realistic estimate, then, the maximum fixed load will weigh about 650 lbs, being the weight of balloon plus gondola and accessories.

The altitude must be at least 55,000 to 60,000 ft; the maximum take-off gross on a 73-ft balloon is about 1500 lbs, meaning that some 850 lbs can be taken aboard as ballast.

C. Balloon Performance

1. General Considerations

The balloon rises from take-off, reaches its initial floating altitude where it is fully extended, valves some lifting gas through its appendix, and then settles down for the long journey in the stratosphere. Each day it loses some gas, by processes to be discussed below, and the loss of gas corresponds to a daily loss of lift. If this loss of gas is a constant fraction of its gross load remaining, γ, then the total duration in days, D, will be given by:*

$$(1-\gamma)^D = F/T \qquad (1)$$

* An alternate form which is sometimes used, corresponding to a continuous process for the loss of lift, is $e^{-\gamma D} = F/T$

The two give about the same answer when $\gamma \ll 1$ for normal values of F/T.

where F is the fixed or final load and T is the total gross load on take-off (1500 lbs), which is clearly F plus ballast.

To illustrate the variation of controlled duration with γ Table 1 presents a representative set of values. An $\frac{F}{T}$ value equal to .43 represents the flight weights stated above; a value equal to .37 represents a decrease in gondola weight of 100 lbs (the decrease taken up as ballast); a value equal to .39 represents a decrease in gondola weight of 100 lbs thereby reducing the entire load. The 12% value of γ represents a "guaranteed value." The 8% value is approximately the theoretical limit attainable with present constant level balloons, while the 15% represents a pessimistic value which would almost certainly be substandard. (These variations of γ are discussed below.)

Table 1

γ \ F/T	.37	.39	.43
.15	6.6 days	6.3 days	5.6 days
.12	8.3 days	7.8 days	7.0 days
.08	12.4 days	11.8 days	10.5 days

It appears that within this entire range of possibilities, with the possible exception of the worst possible case (a γ of 15% and an F/T of .43) the required 6 to 8 days' duration can be realized.* This is the basis for the statement that the job can be done now. The discussion which follows is therefore about ways of increasing the margin of safety and the range of conditions under which the job could be done.

2. Possible Improvements

The equation above shows what factors determine the duration, D.

* This is illustrated in Figs. 10 and 11, which represent theoretical flights using an airtight appendix, and a γ in the first case of 15% and in the second of 8%.

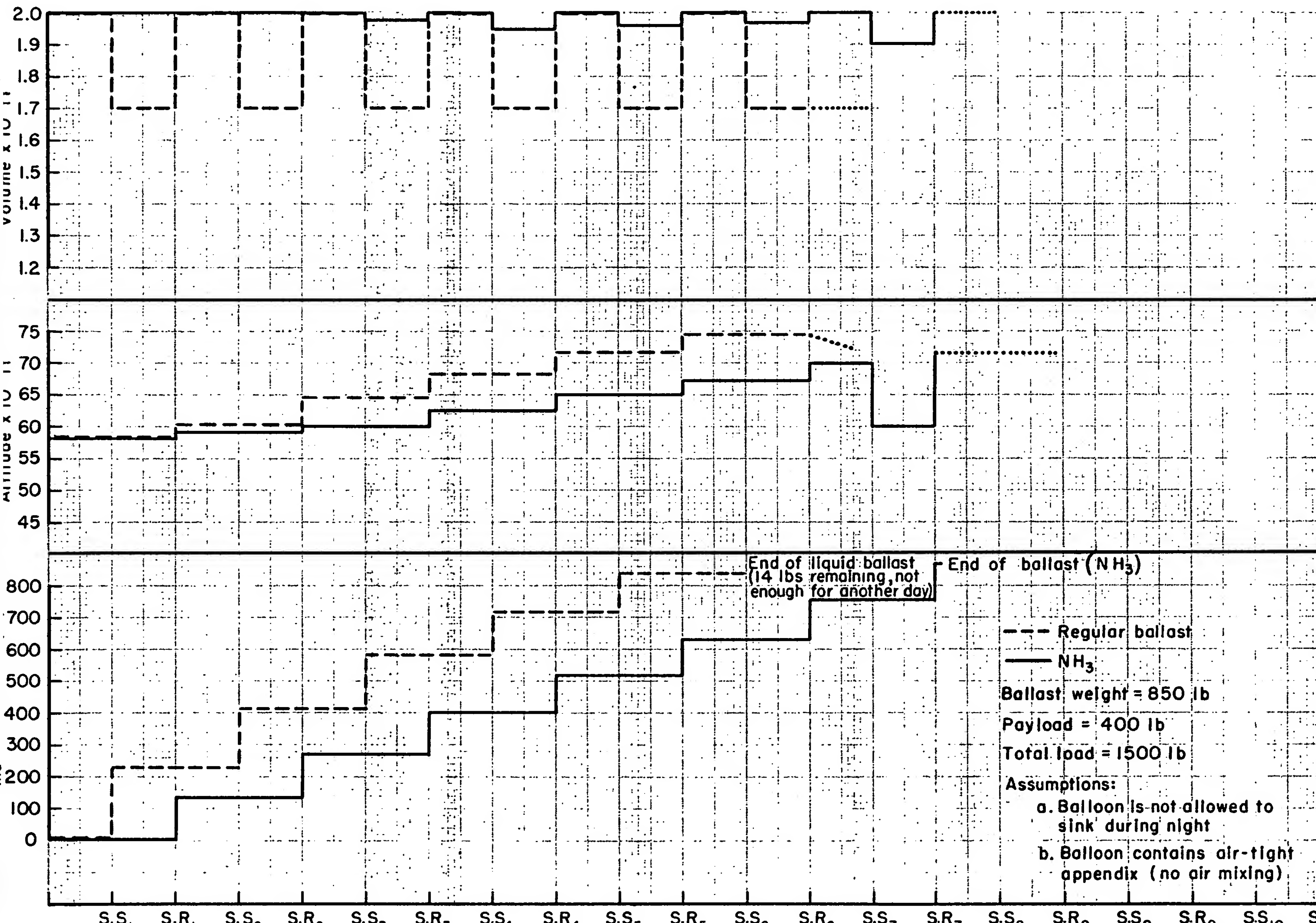


Fig 10—Performance of a balloon with a daily fractional loss of lift = 15 % of gross load

RM979-10

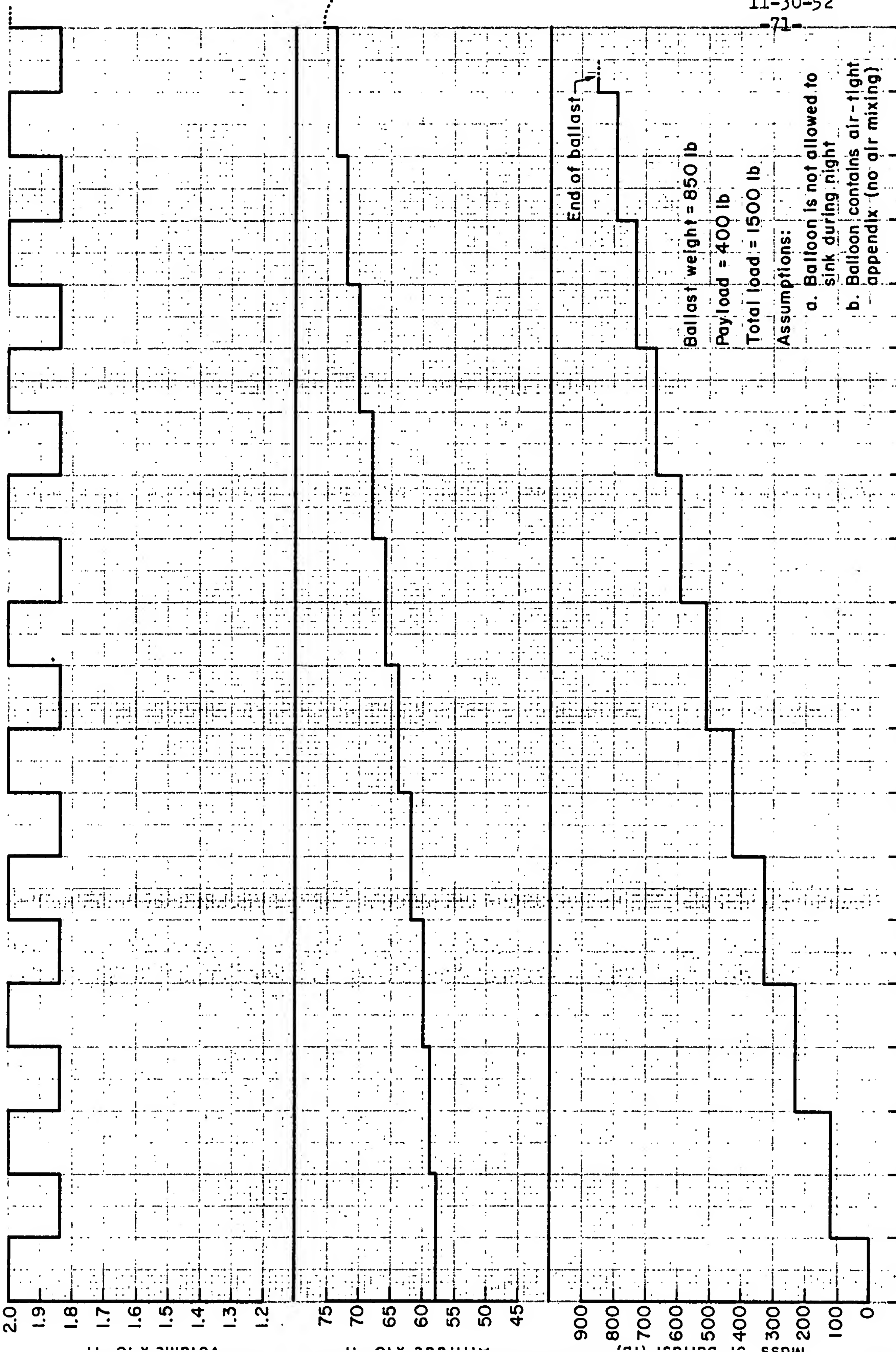


Fig. 11— Performance of a balloon with a daily fractional loss of lift = 8 % of gross load

RM979-11

Clearly, by lowering the ratio F/T the duration will improve, and this can be done either by cutting down on the fixed weight by better design of the gondola or by increasing the gross take-off weight (or both). The latter would mean using a larger balloon in order not to decrease the floating altitude.

These are obvious measures, and are being considered carefully by the project personnel. There is a real possibility for improvement by refining the gondola design and decreasing its weight. This decrease in weight would also make launching and recovery easier.

The other parameter which can be improved is γ, the daily loss of lift. This involves a number of processes so it will be necessary to treat it in some detail. The two general reasons for a loss of lift are:

- Loss of lift due to leakage or diffusion of the gas, usually a slow and continuous process, called γ_L.
- Loss of lift due to a diurnal cycling of the temperature of the lifting gas, called γ_S. The cycle goes like this: At sunset there is a decrease in the radiation being intercepted by the balloon and a corresponding decrease in temperature (for present balloons, this amounts to 10° to 12° C, or about a 5% loss of lift). If the balloon is to avoid sinking (more about this below) there will be a dropping of ballast until the loss of lift is compensated. At sunrise the following morning the balloon regains its superheat and a corresponding excess lift. This excess lift is just overcome by a valving of gas after the balloon is fully extended at its ceiling. Thus, there is a net loss of gas each day.

Methods for Decreasing Leakage and Diffusion. γ_L

Apparently the leakage through the walls of the balloon has been reduced to between 2 and 5 percent. This has been brought about by cutting down gas leakage through a combination of improving the sealing of all seams in the balloon, and utilizing thicker material (.002 inches). In connection with this later improvement, recently balloons have been built utilizing a double wall. This double wall has been achieved by placing together two sheets of polyethylene each 1 mil thick. Due to the fact that a large percentage of the gas loss is caused by diffusion through minute pin holes in the fabric, it was felt that the double wall construction would reduce this form of loss because of the low probability of a hole in one wall lining up with a hole in the second wall. Although not completely flight tested, this technique appears to offer some promise of improvement. An examination of ballast usage of several MOBY DICK flights using 72.3 foot balloons (2.5 mils thick) have shown a very low rate of gas leakage. In one case where there was a noticeable gas leakage; the fractional daily loss was computed at about .06, which puts it just outside of the limits mentioned above. (A second case exhibited a loss of lift of about 15 lbs/hour, but this was attributed to large leakages caused by damaging the balloon prior to launching.)

An additional cause of loss of lift is by diffusion through the appendix. It has recently been realized that this is a serious factor, and the University of Minnesota has designed and built a type of appendix which decreases the diffusion loss. The new appendix has still not been tested on any very long duration flights, but offers great promise in short duration flights (about one day or less, and utilizing no ballast).

Methods for Decreasing the Sunset-Sunrise Loss, γ_s

As was stated above when defining γ_s, the loss is due to the cyclic change in superheat in going from day to night and back to day. In order to decrease the effect of this cyclic change, one can either decrease the amplitude of the change itself (by changing the radiational heat budget), or one can introduce a large damping factor so that the effect on the balloon's altitude will be less. Each of these alternatives has been considered to some extent by both General Mills, Inc., and the University of Minnesota.

- Damping the Vertical Motion:

  Recently the people at General Mills, Inc., have reported a new technique which appears to free us from the penalty of the large superheat compensation each sunset. This is what they call the "solar engine" effect. At sunset the balloon, with an unbalance due to loss of superheat, will sink towards the ground unless a compensatory load is removed from the system. In this case one has one of two choices, either to throw off enough ballast (equal to the total unbalance) to keep the balloon at altitude, or to expend just enough ballast so that the downward velocity of the balloon is not enough to take it below a specified altitude by the next sunrise. An experiment was performed on the newest "Gopher" vehicle (116 feet in diameter), carrying a load of 1700 lbs at an altitude of 70,000 ft, and successful results were reportedly achieved utilizing the second scheme. Furthermore, this performance was repeated with similar loads and similar altitudes on several occasions when flying under the "solar engine" system. To

operate under this principle, the General Mills people used an autopilot control that would not permit the balloon to sink at a velocity greater than 50 ft/min, and set a minimum altitude of sinkage at 40,000 feet. In other words, ballasting was utilized to slow the balloon down and to keep it above the minimum altitude, but not to maintain altitude exactly. In the number of times that this was tried, the average ballast expenditure each day was telemetered as approximately 2 percent of the gross load present at that time, which means that the total ballast expenditure was apparently approximately just equal to the fractional loss due to leakage and diffusion.

This result, which is rather impressive, must be qualified by noting that the small expenditure of ballast was accomplished by a steady decrease in the daily maximum altitude. This was due, in all likelihood, to diffusion through the appendix, and would not be tolerated in a Gopher vehicle. Moreover, it should be mentioned that the flight tests and theoretical calculations of the University of Minnesota seem to indicate that the solar engine will not work--this argument has clearly to be resolved before one can accept the principle.

The success of the solar engine principle depends on taking advantage of the natural thermodynamic stability of a balloon in the stratosphere. This thermodynamic stability is increased by carrying more air along with the balloon, since in descending there is a retardation effect due to the adiabatic heating of this extra air. The amount of air taken in by a balloon with an open appendix is hard to determine, but it would help

to explain the effectiveness of the General Mills solar engine flights.*

Although it is desirable to have this retardation effect, it is not desirable to have the lifting gas mix with the air, since such mixing will cause a change in the molecular weight of the lifting medium and cause a progressive (daily) lowering of the maximum altitude, as mentioned, of the balloon. However, recognizing the possibilities of such a retardation, the people from the University of Minnesota have shown theoretically that by keeping a balloon at constant volume by means of air entrainment of the velocity of such a descending balloon will be proportional to $(\text{pressure})^{-5/3}$. In other words, the further the balloon sinks, the lower will be its velocity. Furthermore, cognizant of the undesirable result of mixing the gas and air they have considered using a "balloon-within-a-balloon" method, of a sort of ballonet. Essentially, this is a balloon that contains the gas and is sealed off from the atmosphere by means of a one-way valve (gas out, no air in), inserted in a second balloon that contains no gas and is open to the atmosphere. As the gas cools and the system sinks, the volume of the inner balloon will decrease, whereas air will be taken into the

* The General Mills people report another tested method for increasing the duration of a flight. This is their so-called "air glide" method. In this method, the appendix is removed after the expenditure of ballast, and the air is allowed to pour into the balloon as it descends. They report that the rate of descent is sufficiently slowed up by this "ram" air that flights have been extended 2-3 days after complete exhaustion of ballast. (This method of course requires a considerable spread between the altitude of the balloon at the time of ballast exhaustion, and the tropopause.) This demonstrates that the contribution of this "ram" air on the balloon performance is not small.

surrounding envelope, if it can be kept distended, thereby maintaining a constant overall volume. Upon regaining its superheat on the following morning, the expanding inner balloon will force the air out of the outer balloon as they both rise. Although not tested or built at this writing, this system is an example of the sort of development which offers considerable promise for the future.

o <u>Decreasing the Radiational Effect:</u>

The balance between the amount of heat that the balloon receives from external sources and the amount it loses by radiation and conduction determines the temperature of the system. This balance can be expressed by the following equations:

$$\dot{Q}_s + \dot{Q}_e = \dot{Q}_r + K_1 \frac{\Delta T_1}{T_1} \quad \text{(daytime)} \qquad (2)$$

and

$$\dot{Q}_e = \dot{Q}_r + K_2 \frac{\Delta T_2}{T_2} \quad \text{(nighttime)} \qquad (3)$$

where, $\dot{Q}_s$ is the heat gained from the sun's radiation; $\dot{Q}_e$ is the heat gained from the Earth's radiation in the infrared; $\dot{Q}_r$ is the heat lost by radiation from the balloon; and $K\frac{\Delta T}{T}$ is the heat gained or lost by conduction (the sign depending on the sign of ΔT, the difference between the balloon temperature and the ambient air temperature). As can be seen, the diurnal variation in lift due to changes in temperature can be reduced in two ways. First: By decreasing the contribution of the sun. Second: By increasing the conductivity of the balloon

to the extent that ΔT is always very small.

In the present system one is faced with a conductivity that is large, but not large enough to overcome the superheat, and a substantial absorption of radiation from the sun--the diurnal variable. As a result of this, every sunset the gas in the present Gopher balloon cools by 10° to 12° C and loses lift to the extent of 5% or more of the remaining gross load. In an effort to reduce the sunset ballast penalty, the people at the University of Minnesota are examining several possible modifications of the present system based on the above reasoning.

Although they have examined the conductivity effect theoretically to establish a better understanding of the processes involved, it is not felt that much promise of improvement lies along these lines. The emphasis has, therefore, been placed on reducing the effect of the sun's radiation. Two main possibilities have evolved from this effort. First, they have found that the tapes that help to hold the balloon together are one of the chief absorbers of solar radiation. In this connection, the University of Minnesota is attempting to build and fly a tapeless balloon. Second, balloons have been flown utilizing NH_3 (ammonia) as the lifting gas, (NH_3 exerts a lifting force somewhat less than helium or hydrogen.) A possible advantage of NH_3 is the fact that it has a much higher absorbtivity in the infrared (region of the radiation from the earth) than in the visible (region of solar radiation), and therefore should not be as much affected by a sunset as would a balloon relatively

transparent in the infrared.

Although both tests are as yet incomplete, one interesting effect has been noticed in utilizing NH_3 that may limit its use. Apparently, there is so close a radiational coupling between the earth and a balloon filled with NH_3, that the altitude is affected as it passes over regions of different "radiation temperatures" (lakes, plowed country, cloud decks, etc.), so much so that it is conceivable that in actual usage one might be faced with a situation that is almost as bad as the sunset effect in the present system. As was stated, however, these results are as yet tentative, and both systems must undergo considerably more testing before a decision is made.

3. Gas Replenishment

The principle of overcoming the loss of lifting gas by replenishing it from a source carried along in the form of ballast is very attractive, and was considered in the original RAND study. However, there are certain practical problems to be overcome, most of them centering about the weight of the container which can hold lifting gas under pressure or in a liquid form for the required duration and quickly provide gas when needed. It should be borne in mind that the replenishment is not a steady process, but takes place mostly at sunset, so the system must be capable of providing a rather large volume of gas in the space of an hour or two (some 1000 ft^3 at STP is required to overcome the sunset loss in present balloons), and then it must almost close down for the rest of the twenty-four hours.

The advantage, in principle, of using a condensed lifting gas as ballast is considerable. In connection with using NH_3 as the lifting gas, a preliminary examination has been made at RAND of the possibility of vaporizing liquid

NH_3 to replace the gas in the balloon rather than dropping liquid or solid ballast. The reasoning behind this study was that, since even for large concentrations of NH_3 in a mixture with hydrogen the mixture density is not very different from that of hydrogen alone, considerable saving might be made by replacing the lost or contracted gas (so as to keep the volume constant) rather than just lightening the load. It was subsequently found that for a given loss in volume at sunset, the weight of liquid NH_3 that was required to replace the lost volume was less than the ballast that would have had to be thrown off in the normal case. To see more clearly how this would work out, a complete flight was run through on paper under the same conditions used previously (1500 lbs - total load, 850 lbs - ballast, fractional loss of lift per day equal to 15% of remaining gross load), but substituting liquid NH_3 for the ballast. The results of this run-through are presented as the solid lines on Figure 10. As might have been expected, NH_3 gave a duration that was greater by a factor of about 1.4 over that achieved with regular ballast.

It should be noted that, although this appears to work very well on paper, its actual accomplishment might be somewhat tricky. This is due to the heat necessary to vaporize the liquid NH_3 when the ambient temperature is about -55° to -60° C. The latent heat of vaporization can be supplied from a heat source attached to the balloon, or it can be provided by storing solar heat. The latent heat of ammonia is quite large (340 cal gm^{-1}), so providing heat by a fuel or from batteries seems impractical. The alternative of storing the solar energy in a heat reservoir has possibilities, especially if the heat reservoir can be the liquid ammonia itself, which has a moderately high specific heat (.502 cal gm^{-1} $^{\circ}C^{-1}$). For example, to vaporize about 10% of the total load of NH_3 one would have to cool the NH_3 by about 68°C. Even if the liquid NH_3

can gain this much superheat from the sun and release it after sunset, thereby requiring no external heating, it will mean that it must be kept in a container that can withstand an internal pressure of over 2.5 atmospheres (or over 35 lbs/ in.$^{-2}$). Although this is not entirely unreasonable, it is conceivable that this extra container weight could reduce the amount of NH_3 that might be carried to the point where the system had no great advantage over straight ballast. However, even if this were the case, the reduction in superheat due to the presence of the NH_3 gas mixture could swing the pendulum back in favor of NH_3 as a ballast.

It should be remembered that the above discussion represents only a preliminary study, made for the purpose of illustrating a possible method, and without complete testing these results have very limited significance.

2. Launching the Balloon

In the final analysis, the difficulty of launching may be the limiting factor in the system design. This has been demonstrated explicitly in all the test work performed on this type of balloon. For example, in the case of the 73 foot diameter balloon, with no facility for reefing or restraining it, experience has shown that it is impossible to inflate vertically (in the absence of a shelter) in a wind of greater than ~ 2 knots. This is due to the large amount of limp or free fabric that tends to form a very efficient sail under the influence of even a moderate wind, resulting in a combination of extreme loads on both the balloon and the hold-down lines. As may be imagined, this is also true of larger balloons, though somewhat magnified, the forces increasing approximately proportional to the radius squared. This effect has been partly remedied by the use of a "reefing tube." In essence, this is a narrow cylinder of polyethelene which, during the inflation period, contains all of the balloon with the exception of the filling bubble. This has the effect of reducing the effective area presented to the wind and, thereby the wind forces.

It is possible to approximate the actual forces experienced by a reefed balloon if one makes several simplifying assumptions.

- o For the purpose of calculating the force on the balloon due to the wind, a first approximation can be arrived at by means of the well-known equivalent flat-plate area method.
- o Use of the flat-plate method requires that the reefed balloon be considered a rigid structure. Although this is obviously not true, it is reasonable when accompanied by the next assumption.
- o Wind velocity is constant over the entire length of the standing balloon, and the wind is not gusty.

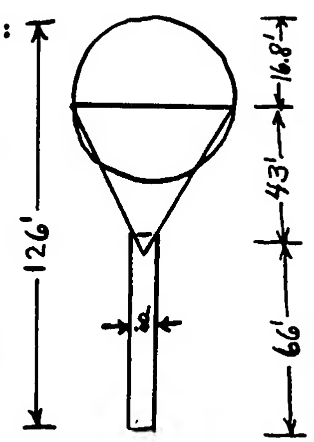
There is no vertical component of the wind force, so the vertical component of the tension in the line is constant at 1500 lbs.

The equation that can be used to calculate the force due to the wind is as follows:

$$F = 1.28 \frac{\rho}{2} a V^2$$

where F is the force in lbs; a is the flat-plate area; ρ is the density of the air in slugs per cubic foot; V is the wind velocity in feet per second; 1.28 is a correction factor to take care of the deviation from theory due to air being pocketed and compressed and the burbling at the rear of the plate.

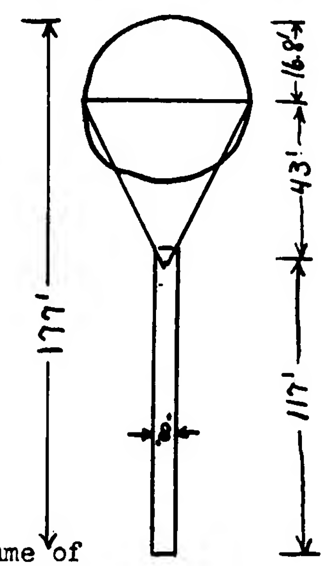
For a "reefed" balloon, one may think of the vehicle as consisting of a cylinder (the reefed section) surmounted by a sphere (the bubble) on a cone. For a 73 foot diameter balloon, the following dimensions* apply:



Reefed section	radius = .8 ft length = 66.0 ft cross sectional area = 106 ft^2
Spherical bubble	radius = 16.8 ft cross sectional area = 888 ft^2
Cone	altitude = 43 ft cross sectional area = 731 ft^2 (including one half of bubble)

Total flat-plate area for a 73 ft balloon $\cong$ 1281 ft^2

Dimentions for a 116 foot diameter balloon:



Reefed section	radius = .8 ft length = 117.0 ft cross sectional area = 188 ft^2
Spherical bubble	radius = 16.8 ft cross sectional area = 888 ft^2
Cone	altitude = 43 ft cross sectional area = 731 ft^2 (including one half of bubble)

Total flat-plate area for a 116 ft balloon $\cong$ 1363 ft^2

* A gross load of 1500 lbs is assumed in all cases, so the volume of inflating gas at sea level is always about 20,000 ft^3.

From the above data then it is possible to compute the angle that the bottom part of the balloon will make with the vertical and the total tension on the load line for a given wind velocity. This was done with the aid of the following force diagram and is presented in Tables 2 and 3:

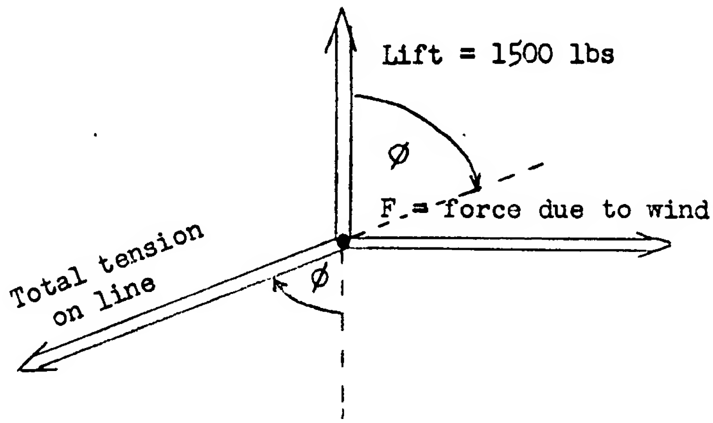


Table 2

Angle of Tilt and Tension in Lines Due to Wind of a Given Velocity on a 73 Foot Balloon

Angle of Tilt from the Vertical Ø	Total Tension in Lines (lbs)	Velocity of Wind (knots)
0°	1500	0
10°	1523	6.9
20°	1569	9.9
30°	1732	12.4
40°	1958	15
50°	2334	17.4
60°	3000	21.5
70°	4386	27
80°	8636	39

Table 3

Angle of Tilt and Tension in Lines Due to Wind of a Given Velocity on a 116 Foot Balloon

Angle of Tilt from the Vertical ϕ	Total Tension in Lines (lbs)	Velocity of Wind (knots)
0°	1500	0
10°	1523	6.7
20°	1596	9.6
30°	1732	12.0
40°	1958	14.5
50°	2334	16.9
60°	3000	21.0
70°	4386	26.3
80°	8638	37.8

It is interesting to note that there is relatively little difference in the wind effect on a reefed 73 foot balloon and a reefed 116 foot balloon with the same gross load. It is unrealistic to assume that this would be true when comparing the unreefed case, due to the relatively large difference in total area (the 116 foot balloon having approximately 2.5 times the area of the 73 foot balloon), and this therefore points out the worth of the reefing system. It should be remembered, however, that this simplified calculation has not considered some other important effects of the wind on a tethered balloon, such as:

- In actuality, the wind velocity will not be constant over the entire length of the standing balloon. (This is not a normal condition near the surface, and it must be assumed that there

is some wind shear at all times when there is a measurable wind velocity.) This means that the balloon will not just "lean", as in the idealized case, but will be subject to a shearing force.

- Due to the inherent turbulence near the ground, the condition of nongustiness is unrealistic. This means that, with its actual non-rigidity, the balloon will be subjected to large transient stress forces, whose directions are random and which tend to vary rapidly.

Therefore, the picture is more complicated than that which was used in the calculations, and the effect of the wind on the balloon is actually magnified by the above mentioned facts. One should not talk of the maximum operational <u>wind</u> velocity, but rather of the maximum operational <u>gust</u> velocity. If one accepts the claim of the General Mills people that a reefed balloon can be launched in a 15 knot wind, it must be assumed that this refers to a steady wind at release time. During inflation, or in fact any holding period, the 15 knots must then refer to the maximum gust velocity. In this case the reported wind, which is a mean value measured over a period of time, can be considerably lower than the maximum gust velocity.

In connection with the maximum velocity at launching, it should be recognized that this value (given above as 15 knots) must be modified to fit the method of operation. If the launching procedure requires that the system be weighed-off before being released (that is, balancing the load against the gross lift to accurately fix the free lift), then the maximum allowable velocity will be considerably less than the stated 15 knots. If this requirement is imposed, to avoid solving a vector equation with several unknowns the balloon should somehow be positioned over the load, and this actually means moving the load on a truck or dolly until it is just under the balloon. In this case, then, a limiting factor is the extent of drivable

land down-wind from the launching platform, the system being moved in this direction to nullify the wind until the weighing off is completed. Since it is impractical to think of moving the gondola cross-country a distance greater than about one-half mile, if it is assumed that the entire driving time (necessary to position, weigh-off, and launch) is about 10 minutes, then the maximum velocity for the case involving a weigh-off is approximately 5-6 knots.

It should here be noted that a division must be made between land based launchings and sea based launchings. Both have been tried successfully, but the sea based launching appears to offer by far the most promising set of conditions. This is due to the fact that a ship can move down wind and establish an essentially no-wind condition over the launching platform. Granted that there is a maximum wind velocity beyond which this is no longer true because of the limited speed of the ship, yet it is obvious that this method will considerably extend the limiting wind velocity for a vertical launching.

Many methods have been suggested to improve the launching capabilities of land stations. In fact, it may be said, somewhat facetiously, that there are as many launching systems as there are people working with balloons. One of the most obvious solutions is the building of a wind shelter to house the balloon during inflation. It must be remembered, however, that this shelter must, first, be capable of containing an object that has a height of at least 120 feet, and, second, it must be omnidirectional in operation. Although it is possible to build such a shelter as a vertical structure, when one considers the problem of multiple operation from the same general area, launching interference makes it impractical. In an effort to solve this problem, the Balloon Sonde Unit, Holloman Air Development Center, has conceived an idea of horizontally containing the balloon during the inflation within a large

"covered wagon" and permitting it to leap free at launching.* Although successful with relatively light loads, up to about 300 lbs, it is doubtful if one can expect the balloon to stand the shock of picking up a heavy load such as the Gopher gondola from what is essentially a running start.

From experience, one can set down the basic requirements for a successful launching system:

1) The system must be omnidirectional
2) The system must provide for a minimum handling of the delicate material of the balloon, both by personnel and by objects (canvas, walls, etc.)
3) The system must provide a minimum shock load on the balloon and gondola at launching.
4) There must not only be a minimizing of the direct wind force, but also of the burbling due to turbulence, which tends to place undue local stresses on the balloon.
5) There should be a minimum of mechanical gadgetry involved in the system, as these tend to reduce the over-all reliability.

As stated, many launching systems have been proposed and several of these have been tried. Full success, however, has not been achieved with any particular one, due primarily to the fact that they violated one or more of the above criteria (mainly 2 and 3).

It can be concluded, then, that with present launching techniques the sea launching base appears to offer the most promise. It should be noted, however, that there are several modifying factors that affect the feasibility of a sea launching base. First, taking into account the speed of an escort carrier (approximately 22 knots), climatological data indicate that, during

* Summary Report on Project Moby Dick Covered Wagon Balloon Launcher, Balloon Sonde Unit, Holloman ADC, Report No. HDT-21, December 1952 (Restricted)

the winter season in the North Atlantic, conditions will permit launching on about 50 percent of the days.* This, however, does not take into account the hindering effect of a disturbed sea which, although highly correlated with strong winds, could conceivably decrease the percentage of usable days. Secondly, it is felt that the supply problem for a sea base might be considerable, particularly from the standpoint of providing lifting gas for a large operation.

Assuming no weigh-off, and utilizing a reefing tube, it may be possible to launch balloons from land locations in gusts up to 15 knots. (It should be noted that this technique has not been completely tested in gusts of this magnitude, and, therefore, this limiting wind speed should for the present be considered as only an estimate.) If this be true, then a cursory examination of surface winds in the United States** indicates that conditions will generally permit launchings on land at least as often as at sea. If the maximum operational gust velocity could be raised to 20 knots, the percentage of usable days over land would increase considerably.

It is estimated that it is possible to launch a maximum of 30 balloons an hour from a carrier. Assuming an 8-10 hour day, over 10,000 balloons could be launched in 50 percent of the days during the three month winter season. It appears, then, from this cursory examination, that it is possible to do the maximum job from a single carrier. In the event of reluctance to commit a carrier (or, for that matter, a seaplane tender), it appears possible to do the job on land with present techniques, though probably requiring more launching personnel and equipment. With improved launching techniques, it appears that the mission could be accomplished equally well on land or at sea,

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* Atlas of Climatic Charts of the Oceans, U.S. Weather Bureau Report No. 1247, 1938

** Airway Meteorological Atlas for the United States, U.S. Weather Bureau Report No. 1314, 1941

there possibly being some edge in favor of the land operation. At present, however, this improved launching method is not available.

The following comparison may be made between sea launchings and land launchings:

	Sea	Land
Maximum operating gust velocity (assuming a "reefed" balloon)	Depends on the speed of the ship - i.e. for an escort carrier, maximum speed is ~22 knots - maximum operating wind velocity is ~20 knots.*	Depends on available shelter, probably not more than 5-6 knots, when weigh-off is required, and ~15 knots when no weigh-off is required.
Security	Good	Poor
Vulnerability to sabotage	Good	Poor
Accessability to supplies	Good, except for gas supplies for a large operation.	Good
Vulnerability to bad weather other than high winds	Fair - bad weather usually accompanied by disturbed sea, which will cut down speed of ship and the efficiency of the launching crews.	Fair - inclement weather will add to the discomfort of the launching crews, resulting in a lowering of their normal efficiency.
Mobility to give better trajectory spread	Good	Poor
Apparent percentage of time base can be operational from the standpoint of winds	~ 50 percent of days during winter season.	Using present techniques and no weigh-off, ~50 percent of days during winter.

The question of the best launching station is therefore not completely resolved. In fact, a much more complete climatological study than was possible here should be made for each proposed launching site, and various promising launching schemes should be adequately tested before arriving at a final decision.

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* Gust velocity is assumed synonymous with wind velocity at sea, due to the fact that gustiness is much less prevalent over the ocean, and in fact the maximum gust velocity here is not very different from the mean wind velocity.

APPENDIX C

RECORD OF THE AIR-SNATCH RECOVERY TESTS

The Aerial Pickup and Delivery Unit, Equipment Laboratory, Wright Air Development Center, has conducted a test program at El Centro, California, to determine the feasibility of snatching a cargo hanging from a parachute, using a method outlined in an informal RAND proposal. Since such a thing had never been tried before systematically,* techniques and equipment had to be developed almost from scratch and procured for the tests. There is still some improvement to be expected before the system is put in operation, but its general features are now fairly well established.

In the tests which have been conducted so far, the following was the usual procedure: The aircraft, a C-119 "Packet" with its rear cargo doors removed, trailing one or two four-pronged grappling hooks on about sixty feet of line, established a power-off glide as it approached the parachute and load. The rate of descent was adjusted to keep the parachute lined up on the horizon, and this assured that the aircraft was at the same altitude as the parachute. In the last few hundred feet of the approach, the aircraft nose was pulled up slightly, and the parachute usually passed fifteen to twenty feet below the plane. As the hook hit the canopy with a violent jerk the line was payed out freely, and the load was then accelerated to the speed of the plane by applying a steady braking force on a special winch in the plane. Usually several hundred feet were payed out before the line

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* A project was established at Wright Field to do this toward the end of World War II, but the project was cancelled before the tests were completed.

stopped running, and the load was then reeled into the plane.

This very brief description of the process omits many of the essential elements, and there were a number of problems which had to be overcome before the scheme was successful, e.g., proper design of the hooks, arrangement of the nylon rope for rapid pay-out, adjustment of the brake setting, procedure for lifting a heavy load into the plane, etc. Moreover, parachutes were usually not properly designed for this. Many were not stable enough in their descent and tended to glide erratically sideways, and sometimes the hook pulled right through the chute, tearing it so badly that it collapsed and "streamed in." The use of improper parachutes was the primary cause of the failure to get good results on the first set of trials at El Centro. The standard medium sized cargo chutes used were hopelessly unstable and weak, and it was only with luck that a few contacts were made. However, the series of tests in May, 1952, were all made with large 48 ft cargo chutes, which had much better characteristics, and these tests are therefore more representative.

The following is the report of the Project Officer, Captain T. L. Billen, and the Project Engineer, Mr. C. H. Brown. (Project and E.O. No. R-409-32, Confidential.) The most significant statement is Item C., at the very end of the report:

> On 2 May 1952, C-119C No. 50-135 was flown to El Centro Naval Air Station to conduct further tests attempting to recover descending parachutes.
>
> The following tests were conducted:
>
> a. Trailing a single hook approximately 30 feet below the craft and still using a model 15 All American Aviation pick-up unit, nine flights were made attempting to hook parachutes as they were descending.

1. Parachutes used were of the 48 foot cargo type.

2. Fifteen parachutes were dropped with the following results:

   (a) One parachute streamed in and hit the ground; therefore, no passes were made at this parachute.

   (b) Two parachutes with 200 pound weights attached were hooked and pulled into the C-119.

   (c) One parachute with a 250 pound weight attached was hooked and pulled into the C-119

   (d) Two parachutes with 300 pound weights attached were hooked and pulled into the C-119.

   (e) One parachute with a 250 pound weight attached was hooked, and cable broke losing hook.

   (f) Three parachutes with a 300 pound weight attached were hooked breaking cable and losing hook.

   (g) One parachute with a 300 pound weight attached did not deflate when hooked, pulling off 800 feet of cable, breaking cable and burning up brakes in pick-up unit.

   (h) One parachute with a 300 pound weight attached was completely missed.

   (i) One parachute with a 400 pound weight attached was completely missed.

   (j) One parachute with a 400 pound weight attached was hooked breaking cable and losing hook.

   (k) One parachute with a 300 pound weight attached rolled off cable above hook, resulting in no hook-up.

b. The 48 foot parachute used on these tests weighed 138 pounds each, which is 73 pound heavier than parachutes used on previous tests.

1. Maximum gross weight recovered on previous tests was 165 pounds.

2. Maximum gross weight recovered on this test was 438 pounds.

3. Desired gross weight for recovery is approximately 565 pounds.*

The following data were reduced from this test:

a. 35.7 percent of parachutes were recovered.

b. 85.7 percent of parachutes were recovered, hooked or contacted.

c. 85.7 percent of parachutes could possibly have been recovered if pick-up equipment was improved to withstand greater loads.

Another series of tests were scheduled to take place in November, 1952, at El Centro. A new pilot, who had not been briefed by the previous pilot (Captain Billen), attempted to duplicate the recovery maneuver. On one of his passes he apparently stalled out as he pulled up to clear the chute and ran right into it, wrapping the canopy and shrouds around one of the propellers and nearly pulling the engine off its mount. The aircraft was landed safely, however, and no one was hurt. The tests will continue when repairs have been made, it is understood.

The obvious lesson to be learned from this experience is the need for carefully training the recovery pilots and crews. A training program would have to be a part of any Gopher operation.

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* The information given the Equipment Laboratory seems to have been a little pessimistic with regard to the Gopher Project requirement. Actually, it now appears that the Gopher package which has to be recovered may be reduced to about 400 lbs (about 300 lbs of gondola plus 100 lbs of parachute and shroud lines). Thus, they have already succeeded in handling the requisite load.

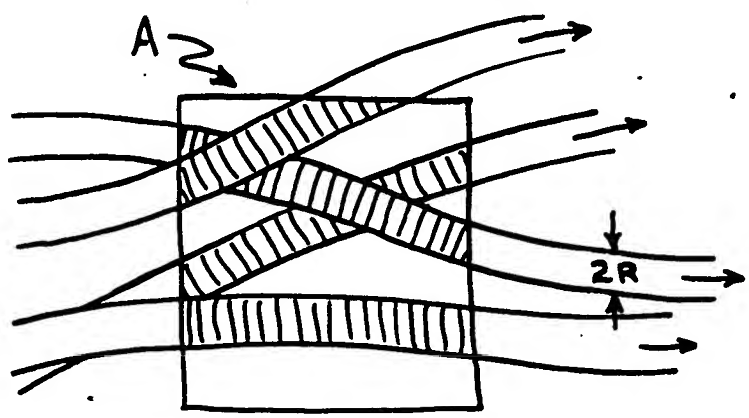
APPENDIX D

CALCULATIONS OF COVERAGE

1. Statistical Treatment of Coverage: The Method

In Section II. E. the method for calculating the fraction of a given area of Russia which would be covered by n effective balloons was briefly outlined. It was devised originally by Dr. T. E. Harris (RAND Mathematics Division) for the earlier report, RM-494, and is described there.*
However, it was used with certain modifications in this revised study, and so it is felt worthwhile to present the statistical treatment in some detail for future reference.

A point on the ground is "covered" if it lies within a certain distance, R (in this case R is 30 mi), of the path of the balloon. In a sector of area A, then, crossed by a number of trajectories, there will be a certain sub-area, A_c, which is covered (hatched) and a certain area which is not covered.



It is the fraction of the area which is covered, $C = \frac{A_c}{A}$ which is called "the coverage".

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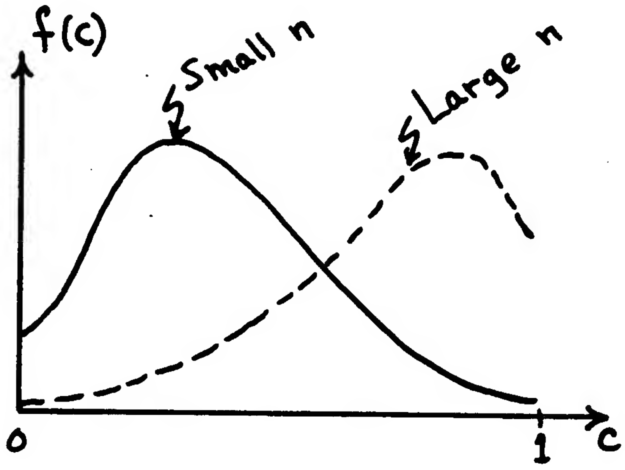
* The method was also treated in a paper presented at the U. S. Weather Bureau Symposium on Meteorological Trajectories in Washington in January, 1952, by W. W. Kellogg.

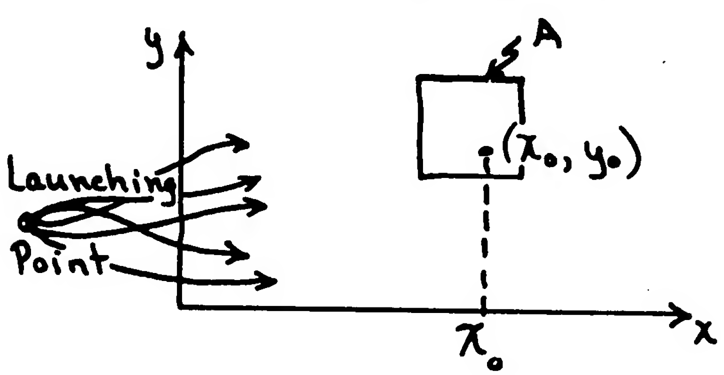


Clearly, since the trajectories are a random process, there will be a finite probability that C is either 0 or 1, and a continuous probability distribution f(c) in between. Rather than dealing with such a continuous probability distribution for the coverage, it is more convenient to specify the mean or expected coverage of the area,

$$\bar{C} = \int_0^1 c\, f(c)\, dc$$

$\bar{C}$ will clearly vary from area to area, depending on the dispersion of the trajectories and the position of the launching point upwind, and it will be larger as the number of effective balloons, n, is increased.

Since it would be difficult to establish f(c) and $\bar{C}$ directly without a very large number of tests and a laborious analysis, a trick is used to obtain $\bar{C}$ from another more easily determined parameter. Consider that



the trajectories are nearly west-east, so that within the element of area A there is no change of coverage with longitude x.

Consider also that the trajectories are independent and random. Let g(x, y)dy be the probability that a single balloon will cross longitude x between latitude y and y + dy. (This is a function which can be

evaluated, as will be shown.) Then, the probability that the point x_o, y_o will be covered by a single balloon is

$$k_1(x_0, y_0) = \int_{y_0-R}^{y_0+R} g(x_0, y)\, dy$$

and if there are n balloons launched the probability that x_o, y_o will be covered by at least one of the balloons is

$$k_n(x_0, y_0) = 1 - \left[1 - \int_{y_0-R}^{y_0+R} g(x_0, y)\, dy\right]^n$$

This is the function from which $\overline{C}$ can be derived, since it can be shown* that

$$\overline{C}_n = \frac{1}{A} \iint k_n(x_0, y_0)\, dx_0\, dy_0$$

It is now necessary, in order to evaluate the probability of the coverage of a point, k_n, to make an assumption about the function $g(x_o, y)$,

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* Intuitive Proof:

Suppose we have a single "random experiment" in which n balloons are launched, and the coverage of A is

$$C = \frac{1}{A} \iint u(x, y)\, dx\, dy$$

where: $\begin{cases} u(x, y) = 1 \text{ when the point } x, y \text{ is covered} \\ u(x, y) = 0 \text{ when the point } x, y \text{ is not covered} \end{cases}$

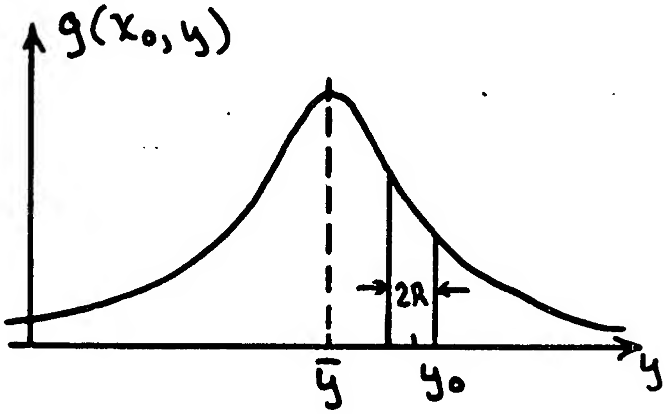
The expected value of the coverage for such an experiment will then be

$$\mathcal{E}(C_n) = \overline{C}_n = \mathcal{E}\left(\iint u\, dx\, dy\right) = \iint \mathcal{E}(u)\, dx\, dy = \iint k_n\, dx\, dy$$

which is true because

$$\mathcal{E}(u) = 1 \cdot k_n + 0 \cdot k_n = k_n$$

which describes the distribution of intersections of trajectories with a given meridian, x_o. This function will be assumed to be a "normal distribution," with a maximum value at some latitude $\bar{y}$, and can therefore be written



in the analytic form

$$g(x_0, y) = \frac{e^{-\frac{[y-\bar{y}(x_0)]^2}{2\sigma^2}}}{\sigma\sqrt{2\pi}}$$

$$= \frac{e^{-\frac{(\Delta y)^2}{2\sigma^2}}}{\sigma\sqrt{2\pi}}$$

$$= \frac{\Phi\left(\frac{\Delta y}{\sigma}\right)}{\sigma}$$

where a simple change of variable has been made:

$$\Delta y = y - \bar{y}$$

and the normal probability function has been introduced, which is:

$$\Phi\left(\frac{\Delta y}{\sigma}\right) = \frac{e^{-\frac{(\Delta y)^2}{2\sigma^2}}}{\sqrt{2\pi}}$$

The integration of this function can be done very easily if the additional assumption is made that R, the radius of coverage of a single balloon, is much less than σ, the standard deviation of the trajectory distribution at a meridian. This is actually quite well satisfied, since R is 30 mi or about 0.5^o, and σ turns out to be in the order of 5^o to 10^o. Thus:

$$\int_{y_0-R}^{y_0+R} g(x_0,y)\,dy = \int_{(\Delta y)_0-R}^{(\Delta y)_0+R} g(x_0,\Delta y)\,d(\Delta y)$$

$$= 2R\,g(x_0,(\Delta y)_0)$$

$$= \frac{2R}{\sigma}\,\Phi\left(\frac{(\Delta y)_0}{\sigma}\right)$$

and the mean or expected coverage of the point x_0, $(\Delta y)_0$ by n balloons is then

$$1-\left[1-\frac{2R}{\sigma}\,\Phi\left(\frac{(\Delta y)_0}{\sigma}\right)\right]^n = k_n(x_0,(\Delta y)_0)$$

2. Statistical Treatment of Coverage: The Calculations

In order to determine the statistical parameters $\bar{y}(x)$ the center of the family of trajectories, and $\sigma(x)$, the standard deviation of the intersections of the trajectories with a meridian at x, some trajectories were plotted from carefully prepared 100 mb U. S. maps drawn at the Department of Meteorology, U.C.L.A.,* using the central tendency method. Launching points were chosen at Lat's. 50° N, 60° N, and 70° N; Long. 135° W. There were nineteen trajectories from each point, one starting every third day, or a total of fifty-seven trajectories. The intersections of the trajectories from a given launching point with each 10° meridian were used to determine $\bar{y}$ and σ, using order statistics. The results are given in the following table.

* These maps were drawn by Dr. H. Kojanski, now with Hqs, Air Weather Service, under the supervision of Dr. J. Bjerknes, and were for the months of January and February, 1949.

Degrees of Longitude East of the Launching Point	Latitude of Launching Point					
	50° N		60° N		70° N	
	$\bar{y}$	σ	$\bar{y}$	σ	$\bar{y}$	σ
10°	45.5°	5.76°	57.2°	2.27°	68.1°	1.97°
20°	41.2	9.88	53.3	5.27	65.7	4.11
30°	41.9	7.52	50.3	6.00	62.0	7.18
40°	41.9	5.30	50.0	5.55	60.0	8.27
50°	42.5	4.71	47.2	4.36	58.8	8.94
60°	43.4	5.75	47.3	4.97	57.6	9.54
70°	43.8	6.75	47.4	6.15	57.4	10.46
80°	44.7	9.15	47.5	8.00	58.8	11.51
90°	43.9	10.27	48.3	10.04	59.2	12.79

Some distributions of k_n are shown in Figs. 4, 5, 6, and 7, where n has been chosen as either 50 or 100 effective balloons, and the launching points have been transplanted to 0° Long. instead of 135° W Long. (The distributions for the launching point at 65° N Lat. were obtained by using values of $\bar{y}$ and σ at each meridian which were averages of the values for launching points at 60° N and 70° N.)

The effect of changing the launching point can be seen from these figures. The more southerly launching point (60° N) appears to result in a smaller spread of the family of trajectories over western and central Russia, compared with the 70° N launching point, and a correspondingly larger coverage along the center line of the trajectories and a decrease at the edge of the pattern. There is no obvious advantage of

one over the other, unless one can decide whether one would like rather complete coverage of the central part or a rather general and uniform coverage of the whole area.

3. Calculation of the Expected Coverage by Actual Balloons

The previous sections have shown how a certain number of effective balloons, n, will cover a given area in western and central Russia. No account has been taken of the degradation factors due to hours of darkness, clouds, or operational failures. Since these degradation factors are also functions of geographical position, it is necessary to perform a sort of integration process in order to arrive at the expected coverage by a certain number of actual balloons, N.

The degradation factors due to cloudiness, D_c, and darkness, D_d, are shown in Fig. 8. These factors are defined as the ratio of the number of actual balloons to the number of effective balloons giving the same coverage of a given element of area. (See Section II. E. 2.) The degradation factor due to operational failure, D_f, has been taken as two, independent of position. Then, the number of actual balloons, N, which must be launched to give the same coverage of an element of area as n effective balloons will be

$$N = D_d D_c D_f \; n$$

The calculation of coverage by N actual balloons was done by considering elements of area which were generally 5° of latitude by 20° of longitude in size. The resulting coverage pattern is somewhat similar to the pattern shown for the effective balloons, but there is a shift to the south and east because of the more favorable weather and hours of daylight in the south-central part of the continent. The expected coverage of each of these elements is shown in the table below for various numbers of actual balloons. The coverage north of about latitude 70° would be zero for all values of N during this period

(taken as January 15) because of the lack of sunlight, but this situation would obviously improve rapidly with the approach of the spring equinox.

Element of Area		Percent Coverage by a Given Number of Actual Balloons			
Lat.	Long.	10,000	6,000	2,000	1,000
65°-70°	30°-60°	55	42	18	12
65°-70°	60°-80°	70	58	28	17
65°-70°	80°-100°	81	70	32	20
60°-65°	30°-60°	95	92	62	40
60°-65°	60°-80°	94	91	65	40
60°-65°	80°-100°	96	92	73	52
55°-60°	30°-60°	100	100	90	70
55°-60°	60°-80°	99	97	90	65
55°-60°	80°-100°	100	98	93	75
50°-55°	30°-60°	100	100	90	70
50°-55°	60°-80°	100	100	99	88
50°-55°	80°-100°	100	99	96	80
45°-50°	30°-60°	100	99	87	60
45°-50°	60°-80°	100	100	96	80
45°-50°	80°-100°	100	100	98	85
40°-45°	40°-60°	98	93	75	55
40°-45°	60°-80°	100	98	85	65
40°-45°	80°-100°	100	100	99	95

In conclusion, it should be emphasized that the coverage estimates which have been obtained in this way are quite rough, and the method has

not yielded any confidence intervals to go with the expected values. Clearly, there will be some fluctuations in the trajectory and cloudiness distribution from year to year, and these will shift the coverage pattern. Also the fact that the time was chosen arbitrarily as January 15 for the darkness factor should be borne in mind, this being quite close to the winter solstice and the shortest day in the year. However, the estimate of the <u>mean</u> <u>over-all coverage</u> may be fairly realistic, since a mere shifting of the coverage pattern will probably not affect the average value appreciably.

The Moby Dick Project will give data on winds in the stratosphere above 60,000 ft which will be much more reliable than any which were available before. It is recommended that, when these are obtained, a more detailed analysis be made, using a method similar to the one used here but with various combinations of multiple launching points and with a variation of the launching points with the season, i.e., separate calculations for December and for March. The effort spent in maximizing the launching procedure would probably pay good dividends.